INL/MIS-23-72339-Revision-0

Nuclear Science & Technology March 2023 Highlights

May 2023

Addison Marie Arave

Changing the World's Energy Future

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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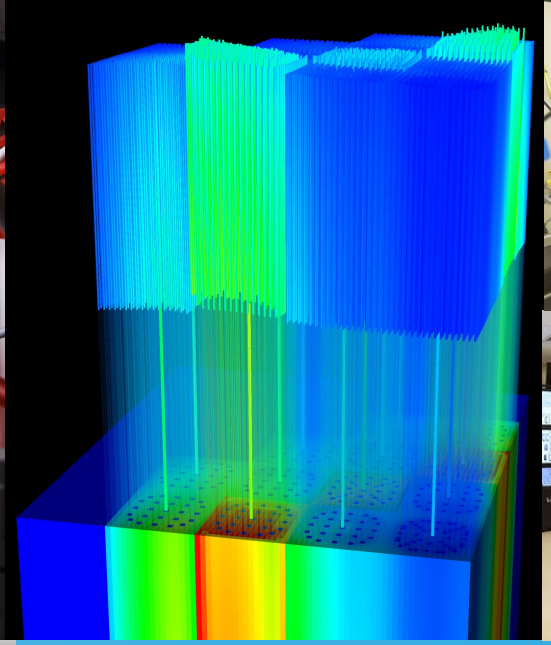
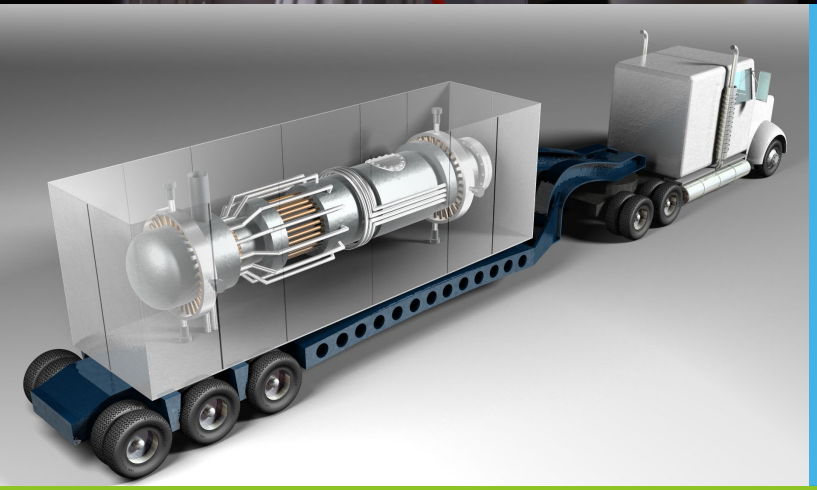


Nuclear Science & Technology

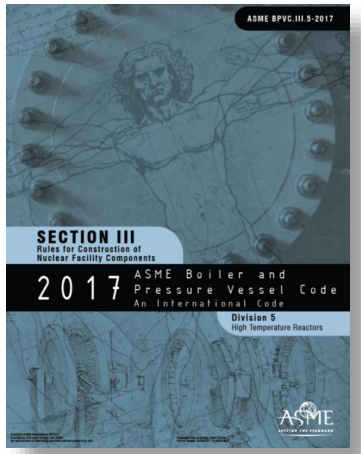
March 2023 Highlights

Idaho National Laboratory

DOE-NE Advanced Reactor Technologies Program

Nuclear Regulatory Commission Endorses American Society of Engineers Section III, Division 5 for the Design and Construction of High Temperature Reactors

- The Nuclear Regulatory Commission (NRC) endorsed American Society of Mechanical Engineers (ASME) Section III, Division 5—High Temperature Reactors, 2017 Edition, with exceptions and limitations, through NRC Regulatory Guide 1.87 (Revision 2) in January 2023
  - The endorsement included new high temperature design evaluation method code cases.
- Division 5 rules govern the construction of vessels, piping, pumps, valves, supports, core support structures and nonmetallic core components for use in high temperature reactor systems and their supporting systems.
- The endorsement of Division 5 by the NRC represents a significant milestone in the reduction of regulatory risk for reactor developers aiming to license their advanced reactors.
- The process began in 2017 when Sam Sham led an effort to garner industry stakeholders support to demonstrate the need for the endorsement of ASME Section III, Division 5 by the NRC
  - Based on the demonstrated need, ASME management formally requested the endorsement in June 2018 and NRC initiated the review effort that August.
- Sam Sham, Chair of ASME Section III Subgroup on Elevated Temperature Design, developed a strategy for engagement with the NRC for the review. The strategy established two task groups, one for metallic components and the other for nonmetallic components. ASME volunteers and NRC staff provided a forum to facilitate an active and engaged dialogue.
  - The task groups published three ASME Nuclear Technical Books in support of Division 5.



Sam Sham, metallic task group chair.

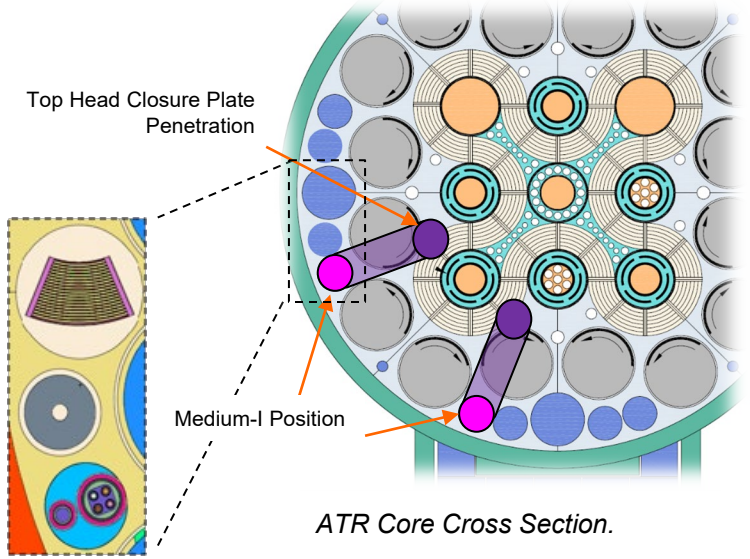
Will Windes, nonmetallic task group chair.

TingLeung.Sham@inl.gov

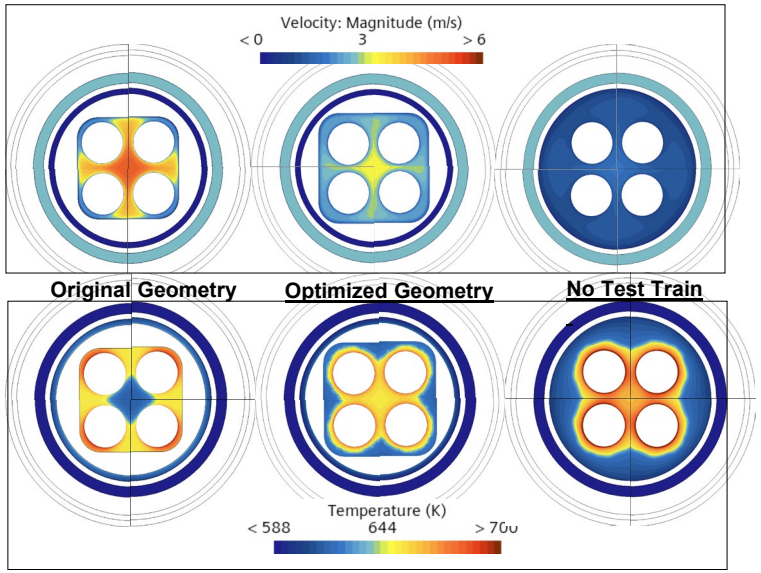
DOE-NE Advanced Fuels Campaign

Thermal Design and Analysis of Advanced Test Reactor I-Loop Facilities

- INL is designing closed loop experimental facilities for the Advanced Test Reactor (ATR) in the medium I-positions (I-Loop). These facilities will provide irradiation testing positions that have neutronic, thermal-hydraulic, and chemistry boundary conditions typical of Pressurized Water Reactors and Boiling Water Reactors operating conditions.
- These ATR I-Loop facilities will be unique world-wide. The Halden reactor in Norway was one of the only facilities with similar irradiation testing capabilities but is currently undergoing decommissioning. These facilities will allow for independent control of flow rate, pressure, water chemistry, and power.
- I-Loop related efforts include a prototype that will allow thermal-hydraulic tests of new designs before irradiation experiments are performed. This will increase safety and operational capabilities quantification.
- Within the multi-disciplinary design activities, the Irradiation Experiments Thermal Hydraulic Analysis (IETHA) department is performing the thermal-hydraulic design and analysis for the test train operational envelope, sizing of loop equipment (such as the pressurizer), electrical heaters, and heat exchangers.
- IETHA staff are performing detailed computational fluid dynamics simulations to optimize test train designs and improve specimen cooling while reducing pressure drop and flow induced vibrations.



ATR Core Cross Section.



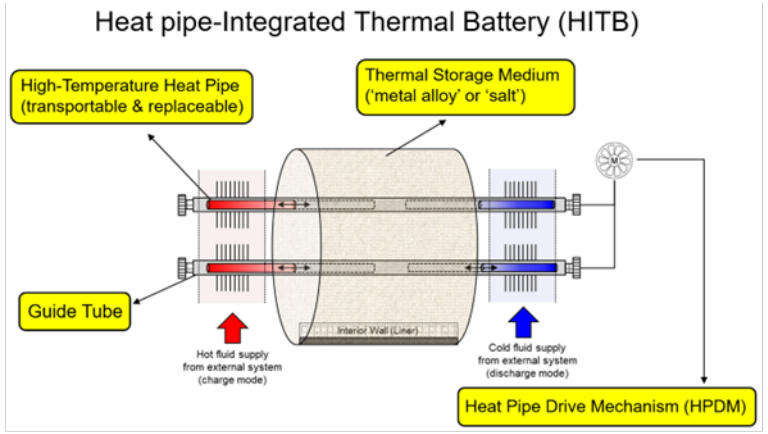
Cross sectional velocity (top) and temperature (bottom) fields for different test train configurations (original, optimized, no test train)

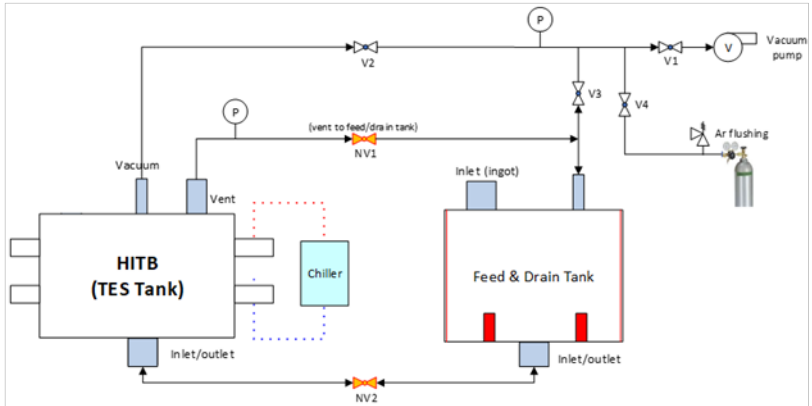
Carlos.EstradaPerez@inl.gov

INL Laboratory Directed Research and Development Program

Heat Pipe-Integrated Thermal Battery Designed for Versatile Integration with Emerging Microreactors

- High-temperature thermal energy storage (TES) is attracting attention as a technology to enhance the overall utilization of high-quality heat and profitability of currently emerging microreactors.
- Heat pipes directly pair microreactors with TES to passively transfer high-quality heat.
- Idaho National Laboratory (INL) researchers proposed a more effective heat pipe called the Heat pipe-Integrated Thermal Battery (HITB) which provides a moveable, internal liquid-filled pipe to transfer heat between units, as shown by the figure to the right.
- Benefits of HITB include:
  - Double heat transfer capacity
  - More flexibility in physical separation between units
  - Reduced regulatory concern by separation between units
  - Easy scalability for multiple HITB modules.
- An experimental facility using HITB will be built at INL during the current fiscal year for experimental demonstration and validation research.





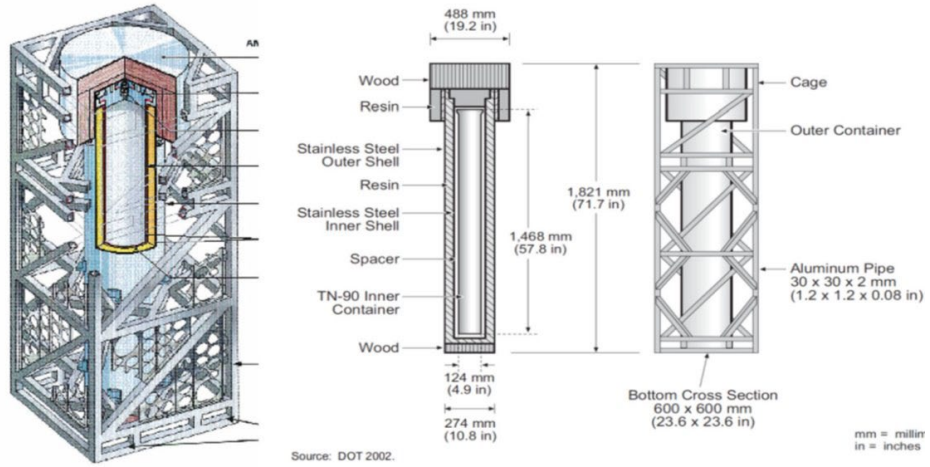
Heat pipe-Integrated Thermal Battery (HITB):
(1) Conceptual design of HITB (top)
(2) HITB demonstration facility to be built at INL (bottom)

JunSoo.Yoo@inl.gov

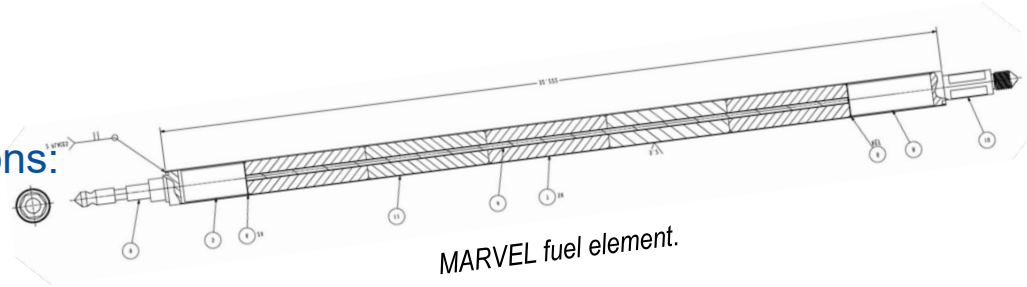
DOE-NE Microreactor Program

MARVEL Project Signs Contract for Cask Recertification for Use in TRIGA Fuel Transport

- Signed on March 16, this contract with Training, Research, Isotopes, General Atomics (TRIGA) addresses the largest schedule risk for the Microreactor Applications Research Validation and EvaLuation (MARVEL) project: cask recertification.
- This agreement is the culmination of six months of negotiation between Battelle Energy Alliance (BEA), Framatome, and General Atomics.
- The recertification will take approximately 18 months and involve French and Canadian regulators, the United States (US) Nuclear Regulatory Commission (NRC) and the US Department of Transportation.
- The MARVEL project can now shift focus to the fuel fabrication contract. MARVEL remains on schedule for startup in late 2024.
- MARVEL will use standard TRIGA fuel with the following specifications:
  - Five UZrH fuel meats instead of three
  - 304 SS clad with standard end caps
  - TN-BGC-1 cask can accommodate this payload, but cask must be recertified prior to use.



TN-BGC-1 cask.



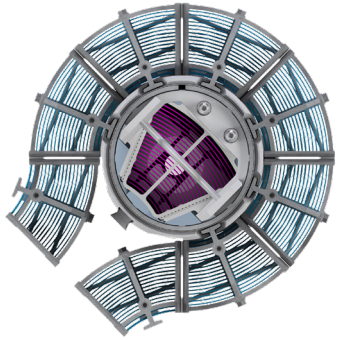
MARVEL fuel element.

MW.Patterson@inl.gov

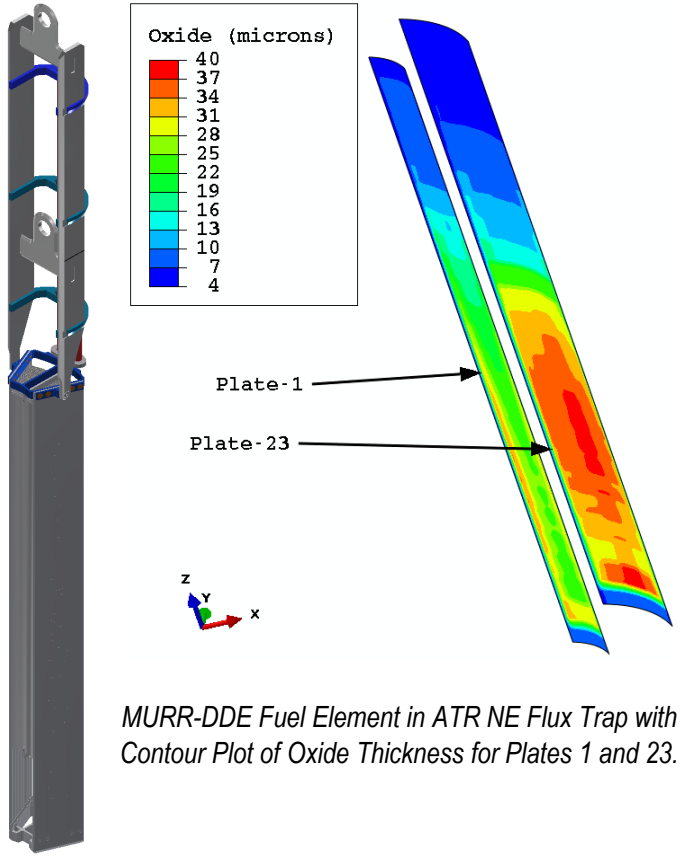
NNSA United States high Performance Research Reactor Program

Researchers Perform Thermal Analysis of the University of Missouri Design Demonstration Element Test

- The objective is to perform thermal analysis of low enriched uranium (LEU) U10Mo fuel in support of irradiation testing for eventual conversion of the University of Missouri Research Reactor (MURR) from a highly enriched uranium (HEU) core to a LEU core as part of the United States High Performance Research Reactor Program.
- ABAQUS software is used to create a 3-D finite element model of the University of Missouri Design Demonstration Element (MURR-DDE) fuel element. The fuel element has 23 curved U10Mo aluminum-clad plates which will be irradiated in the Advanced Test Reactor (ATR) northeast (NE) flux trap.
- The fuel centerline temperature is an important parameter used for evaluating fuel performance.
- Prediction of oxide growth on aluminum cladding using the ATR modified Griess correlation that varies with time and temperature helps to more accurately model the fuel centerline temperatures in the plates under irradiation conditions.
- After irradiation, oxide thickness will be measured and compared with the values predicted by the model.



Drawings of MURR-DDE fuel element and NE flux trap with fuel element courtesy of Greg Housley.



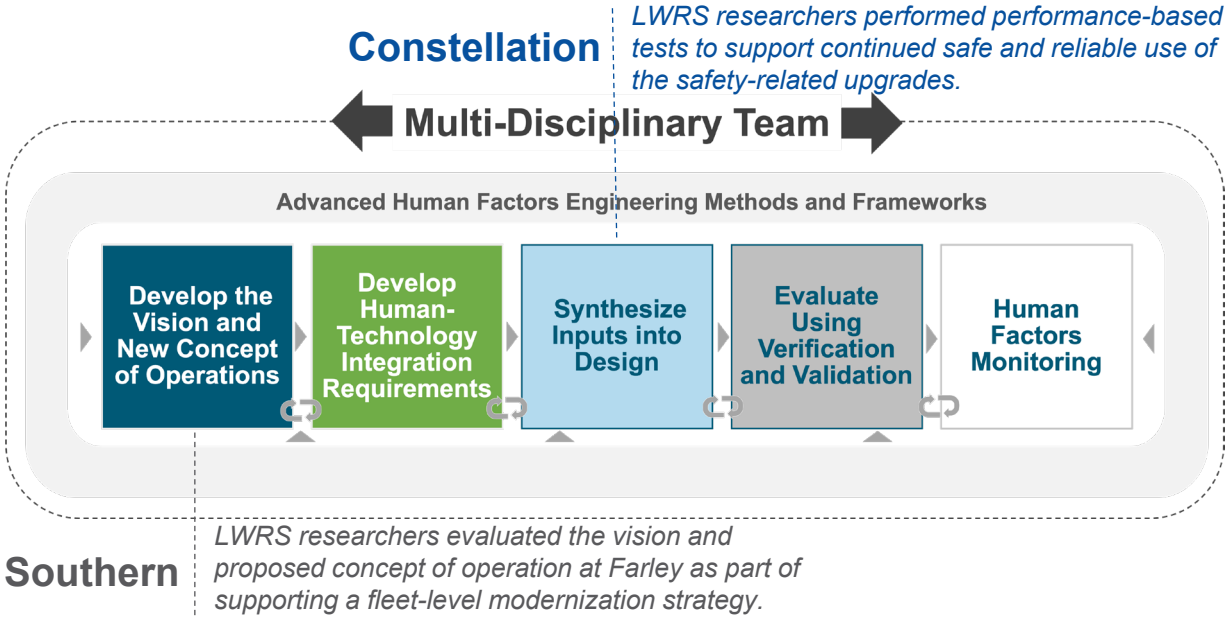
MURR-DDE Fuel Element in ATR NE Flux Trap with Contour Plot of Oxide Thickness for Plates 1 and 23.

REACTOR SYSTEMS DESIGN & ANALYSIS | IRRADIATION EXPERIMENTS THERMAL HYDRAULIC ANALYSIS
Grant.Hawkes@inl.gov, Joshua.Fishler@inl.gov

DOE-NE Light Water Reactor Sustainability Program

Human-Technology Integration Methodology Supports Major Digital Modernization Projects Across Industry

- Light Water Reactor Sustainability (LWRS) Program researchers are helping two United States utilities implement innovative digital control room solutions that go beyond like-for-like replacement by demonstrating the human and technology integration (HTI) methodology.
  - Researchers applied the HTI methodology during the detailed design phase of Constellation's Limerick Safety-Related Upgrade Project to ensure continued safe and reliable operation with the upgraded system.
  - Researchers applied the HTI methodology in the initial scoping phase of Southern's fleet-wide modernization project by developing the vision and new concept of operations for the Farley plant.
- Lessons learned will provide guidance on HTI for the industry, which will reduce the technical, financial and regulatory risk of upgrading the aging instrumentation and control systems. Ultimately, this should support extended plant life up to and beyond 60 years.



Title: Demonstration of the Human and Technology Integration Guidance for the Design of Plant-Specific Advanced Automation and Data Visualization Techniques
Authors: Casey Kovesdi, Jeremy Mohon, Chloe Pedersen-San Miguel (INL)
Link: lwrs.inl.gov/Advanced IIC System Technologies/DemonstrationHumanTechnologyIntegration.pdf

NUCLEAR SAFETY AND REGULATORY RESEARCH | HUMAN FACTORS AND RELIABLILITY
Casey.Kovesdi@inl.gov

LWRS LIGHT WATER REACTOR SUSTAINABILITY

NNSA International Nuclear Security Analytics and Innovation

Leadership Expands Partnerships for Advanced Reactor Security Research and Development

- INL researchers are working to evaluate and mitigate risks for advanced reactors (AR) by design through the National Nuclear Security Agency (NNSA/NA-21) International Nuclear Security for Advanced Reactors (INSTAR) Program

  In late February:

  - INL leadership presented AR security research activities progress to NNSA and NRC leadership.
  - Nuclear Science & Technology Leadership attended the NA-21 program review and analyzed opportunities to enhance partnerships for emerging threat analysis.
  - Opportunities for collaboration between Sandia National Lab, INL, NRC, and NNSA were identified that could:
    - Enhance security for domestic and international AR deployment
    - Provide innovative support for Ukranian critical infrastructure threat reduction
    - Analyze and evaluate emerging uncrewed arial vehicles and drone threat profiles.

Reactor Type	Source	Dose Impact Level	Dispersibility Level	Barrier Level
SFR	Core	Very High	Low	Low
	Cesium Trap	High	Medium	Low
	Cold Trap	Medium	Medium	Medium
	Noble Gas Decay Tanks	Low	High	High
	Fuel Washing Station	High	Medium	Low
	Spent Fuel Pool (Na)	Very High	Low	Low
	Spent Fuel Pool (H2O)	Very High	Low	Medium

Sodium Fast Reactor Systems Qualitative Nuclear Dose Risk Analysis.

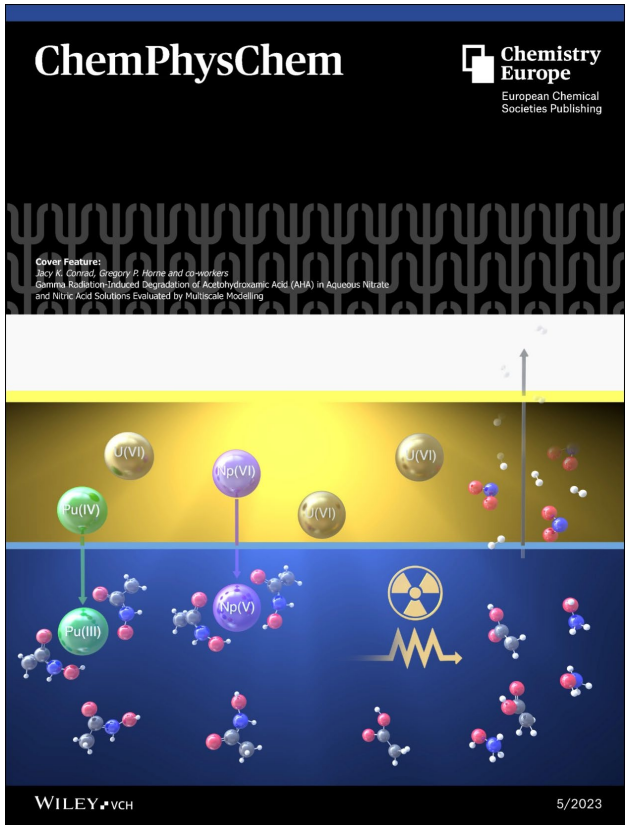
Scott.Ferrara@inl.gov

INS International Nuclear Security
Reducing Risk of Nuclear Terrorism

Program Highlight

DOE-NE Material Recovery and Waste Form Development Campaign

Radiation-Induced Degradation of Acetohydroxamic Acid Featured on Cover of ChemPhysChem Journal



The cover of ChemPhysChem featuring INL collaborative research. Artwork by INL staff member and artist Rett Longmore.

- Acetohydroxamic acid (AHA) has been proposed for inclusion in used nuclear fuel reprocessing cycles for the reduction and complexation of neptunium and plutonium.
- Idaho National Laboratory researchers and collaborators in the United Kingdom have published a journal article reporting their experimental results and presenting computer modeling of the radiation-induced degradation pathways of AHA in aqueous nitrate and nitric acid solutions.
- The cover depicts the formation of AHA degradation products from hydrolysis and radiation in the nuclear fuel cycle.

Title: Gamma Radiation-Induced Degradation of Acetohydroxamic Acid (AHA) in Aqueous Nitrate and Nitric Acid Solutions Evaluated by Multiscale Modelling
Authors: Conrad, J., Mezyk, S., Isherwood, L., Baidak, A., Pilgrim, C., Whittaker, D., Orr, R., Pimblott, S., Horne, G.
Journal: *ChemPhysChem*
Link: doi.org/10.1002/cphc.202300083

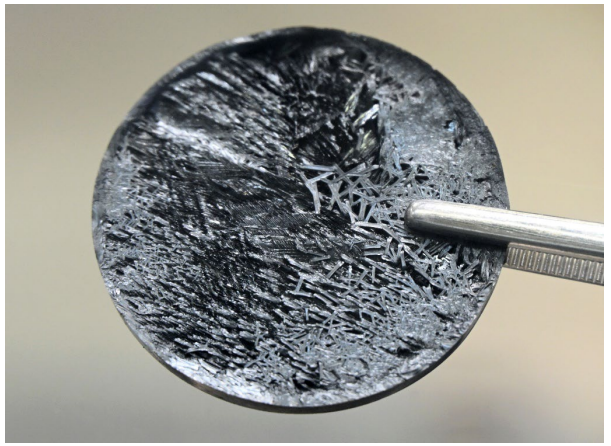
jacy.conrad@inl.gov, gregory.horne@inl.gov

Research Highlight

INL Laboratory Directed Research and Development

First Ever Synthesis of High Enriched Uranium Fuel Salt for Molten Salt Irradiation Experiment

- This synthesis and the subsequent irradiation experiment mark an important step towards the development of molten salt reactors (MSRs).
- A sodium chloride-uranium trichloride eutectic (NaCl-UCl3) was synthesized for the first-time using uranium enriched to 93.17% in U-235.
- This fuel salt will be irradiated in the Molten Salt Research Temperature Controlled Irradiation (MRTI) capsule in the Neutron Radiography Reactor this summer to study fission product distribution, corrosion in MSR environments and the evolution of thermophysical properties of the salt.
- Synthesis work was performed in the Pyrochemistry Glovebox in the Fuels and Applied Science Building, which contains a number of furnaces and other experimental capabilities to support pyrochemical fuel cycle MSR research and development.
- Collaborators include Bill Phillips, Abdalla Abou-Jaoude, Gregory Core, Chuting Tan, Calvin Downey, Stephen Warmann, Morgan Kropp, Kim Davies, Stacey Wilson, SuJong Yoon, Jacob Yingling and Robert Hoover.



First Synthesized Specimen of Highly Enriched $NaCl\text{-}UCl_3$ Fuel Salt.

The Pyrochemistry Glovebox in the Fuels and Applied Science Building.

Fuel Cycle Science & Technology | Advanced Technology of Molten Salts
William.Phillips@INL.gov

Catherine Riddle Receives Icon Award from Idaho Business Review Magazine

- The Icon Awards recognize men and women for a lifetime of community involvement, professional achievement, mentorship and vision. The ICON awardee's have helped Idaho's business community grow and they continue to champion their industry through professional creativity, innovation, and leadership.
- Catherine Riddle is a senior research scientist with expertise in radiochemistry and radiochemical separations. She also 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.

Icon Awardee Catherine Riddle.

FUEL CYCLE SCIENCE AND TECHNOLOGY | NUCLEAR SCIENCE AND TECHNOLOGY
michael.norato@inl.gov
AQUEOUS SEPARATIONS & RADIOCHEMISTRY
melissa.warner@inl.gov

INL Glenn T. Seaborg Institute Hosts the First Seaborg Summit at National Meeting of The Minerals, Metals & Materials Society (TMS)

- INL staff hosted a four-day symposium focused on recent advances in actinide chemistry and physics at the national TMS meeting in San Diego.
- Directors from four other national laboratory Seaborg Institutes joined the symposium for a panel session.
- Over fifty speakers presented research results and invited talks during the well-patronized meeting.
- INL's Seaborg Institute was formed in 2017 with a mission to advance the chemistry and physics of the f-elements. Seaborg Institutes around the country are increasing engagement to achieve common goals of collaboration, advancement of science, and development of staff pipelines.

TMS
The Minerals, Metals & Materials Society

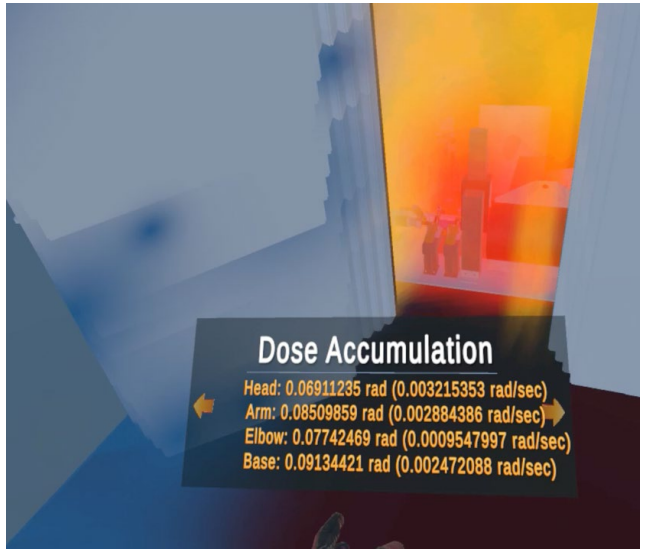
Rory Kennedy, Krzysztof Gofryk, and Don Wood of the Glenn T. Seaborg Institute at INL with other Seaborg directors from across the country.

FUEL CYCLE SCIENCE AND TECHNOLOGY | NUCLEAR SCIENCE AND TECHNOLOGY
michael.norato@inl.gov
AQUEOUS SEPARATIONS & RADIOCHEMISTRY
melissa.warner@inl.gov

National Nuclear Security Administration

INL Presents a Digital Twin for a Mobile Hot Cell Design at Waste Management Symposia

- Computer-aided design experts developed a digital twin to test a mobile hot cell prototype in a virtual reality environment. They used robotic animation to simulate processing steps and performed radiation exposure testing of universal robots UR-5.
- Researchers completed multiple Monte Carlo N-Particle Transport runs to model radiation inside and outside the hot cell throughout the processing steps.
- This research revealed that a robot can complete mobile hot cell processing steps without electronic failure due to radiation exposure.
- These findings uncover a reduced risk to public due to lower radiation values detected outside the hot cell and very low risk of radiation leakage in case of a problem in the processing.
- For this work, a digital twin helped us:
  - Understand the fate of the robot
  - Make improvements to the processing steps (reduced time)
  - Achieve an improved mobile hot cell design that is safer for operators and the public.



Screen capture of time and motion analysis of the mobile hot cell, showing accumulated dose of the robot electronics.

Title: Mobile Hot Cell Digital Twin: End-of-Life Management of Disused High Activity Radioactive Sources
Authors: Khadka, R., Koudelka, J., Kenney, K., Egan, S., Cassanova K., Hillman, B., Reed, T., Newman, G., Isaac, B.
Proceedings: Waste Management Symposia 2023
Link: https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_53418.pdf

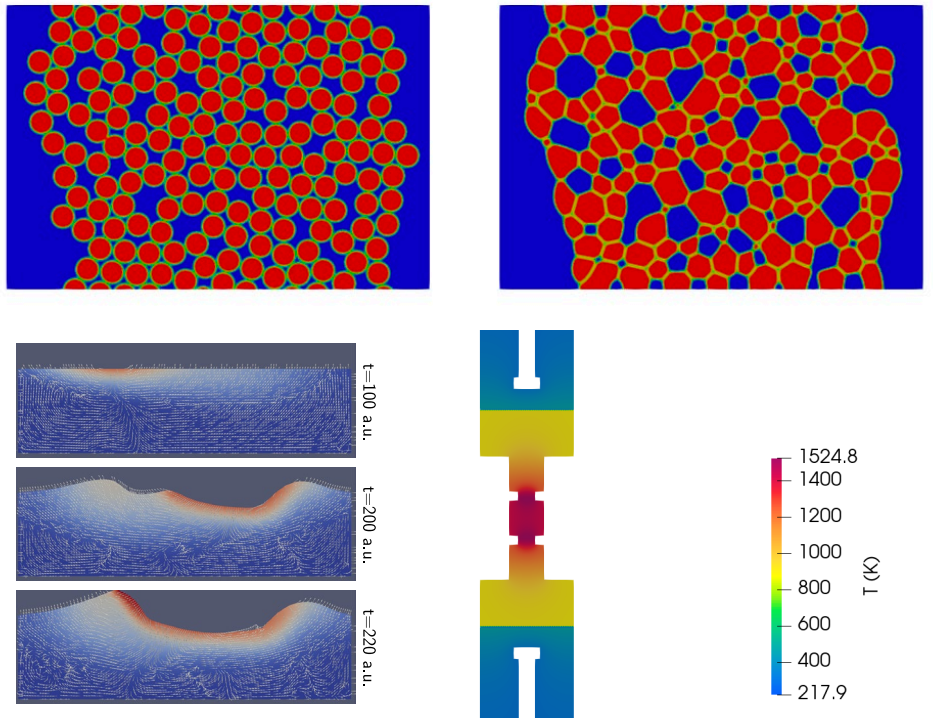
AI DATA ANALYTICS
Rajiv.Khadka@inl.gov

Research Highlight

INL Laboratory Directed Research and Development Program

The MOOSE Application Library for Advanced Manufacturing Utilities (MALAMUTE) Advanced Manufacturing Code Made Open Source

- Advanced manufacturing (AM) techniques can rapidly deliver high-performance and high efficiency parts and materials for a variety of fields, including aerospace and energy.
- Modeling and simulation techniques are vital for understanding and designing AM processes to fit desired product parameters.
- MALAMUTE is a multiphysics simulation code made for a variety of AM processes. It is designed to connect the microscale characteristics and evolution of materials with their engineering scale, post-manufacture performance.
- MALAMUTE, developed internally as part of multiple Laboratory Directed Research and Development projects and used externally in collaborations with National Aeronautics and Space Administration, has recently been made open source at https://github.com/idaholab/malamute.
- Current models include electric field-assisted sintering (EFAS) and laser surface heating (deformation, melting, and welding). Additive manufacturing capabilities are also under development.
- This work provides an open platform for future research in novel materials development and advanced manufacturing technologies at INL.



Examples of MALAMUTE simulations – (bottom left) laser melt pool formation and moving interfaces (A. Lindsay et al), (top) electrochemical model development for EFAS (L. Aagesen et al.), and (right) electrothermal modeling of an EFAS process (INL LDRD 19P45-031FP).

MOOSE

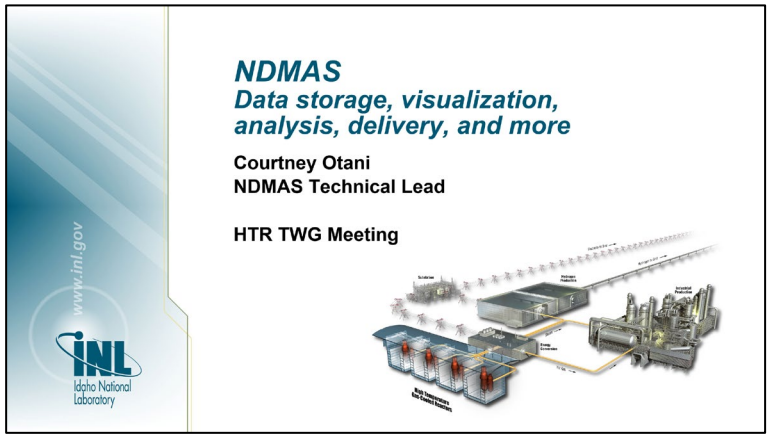
ADVANCED SCIENTIFIC COMPUTING | COMPUTATIONAL FRAMEWORKS
casey.icenhour@inl.gov

IDAHO NATIONAL LABORATORY

DOE-NE Advanced Reactor Technologies Program

Nuclear Data Management and Analysis System Capabilities Presented at Nuclear Energy Institute High Temperature Reactor Technology Working Group Meeting

- The quarterly meeting of the High Temperature Gas Reactor Technology Working Group (HTR TWG) included a presentation by INL staff on the capabilities and value of the INL Nuclear Data Management and Analysis System (NDMAS).
- The meeting included participants from Kairos Power, X-Energy, BWX Technologies, Framatome, the Nuclear Energy Institute (NEI), the Department of Energy (DOE), and the Electric Power Research Institute (EPRI).
- The presentation demonstrated NDMAS as a valuable resource for the HTR TWG and greater technical community. It included an overview of NDMAS processes for handling, analyzing, and delivering data. Examples of the delivery capabilities were shown using data from the Advanced Gas Reactor TRISO fuel development and qualification program.

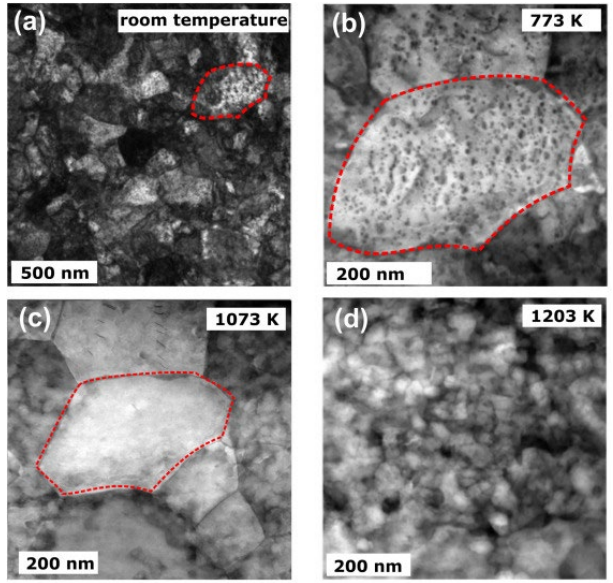


Courtney.Otani@inl.gov

DOE-NE Nuclear Science User Facilities

Researchers Study Alpha Uranium to Better Predict Fuel Performance

- Metallic fuel has regained attention as a candidate for deployment in future advanced sodium-cooled fast reactors.
- The performance of metallic fuel has been demonstrated, but a full knowledge of microstructural and phase evolution during irradiation is still needed. Understanding phase composition and microstructure in real-time, at temperature will provide vital input to predict fuel performance.
- In this study, the hypothesis of temperature being the predominant parameter influencing microstructure evolution was investigated using *in situ* heating transmission electron microscopy.
- Although the experimental results show some differences from previous in-pile test studies, temperature was demonstrated as the predominant parameter influencing microstructural and phase evolution. Computational studies confirmed the *in situ* result and increased confidence in the experimental findings.
- The Nuclear Science User Facilities provided access to the Electron Microscopy Laboratory, the Irradiated Material Characterization Laboratory and the High Performance Computing Center at INL.



Snapshots taken at different temperatures to show the grain structure evolution.

Title: Microstructural and phase changes in alpha uranium investigated via in-situ studies and molecular dynamics
Authors: Fidelma G. Di Lemma, Tiankai Yao, Daniele Salvato, Luca Capriotti, Fei Teng, Andrea M. Jokisaari, Colby J. Jensen (INL), Benjamin W. Beeler (INL and North Carolina State University), Yuhao Wang (University of Michigan).
Journal: Journal of Nuclear Materials
Link: doi.org/10.1016/j.jnucmat.2023.154341

Nuclear Science User Facilities

DOE-NE Nuclear Science User Facilities

Nuclear Science User Facilities Hosts Annual Users Organization Meeting

- On March 23, the Nuclear Science User Facilities (NSUF) hosted a hybrid Users Organization meeting.
- This meeting is critical for the health of the NSUF. The Users Organization serves as an advocacy group for the experimental activities at the NSUF; provides a communication channel among users; and educates decision-makers and the public on the benefits of research on nuclear energy generation.
- The 2023 meeting drew around 100 attendees throughout the day and featured presentations on facility upgrades, core capabilities, workshops, and Q&A sessions.
- The Executive Committee held a town hall and attendees selected committee members for the upcoming year.
- View https://nsuf.inl.gov/Page/nsuo to learn more.

NSUF Director Brenden Heidrich presenting to NSUF users.

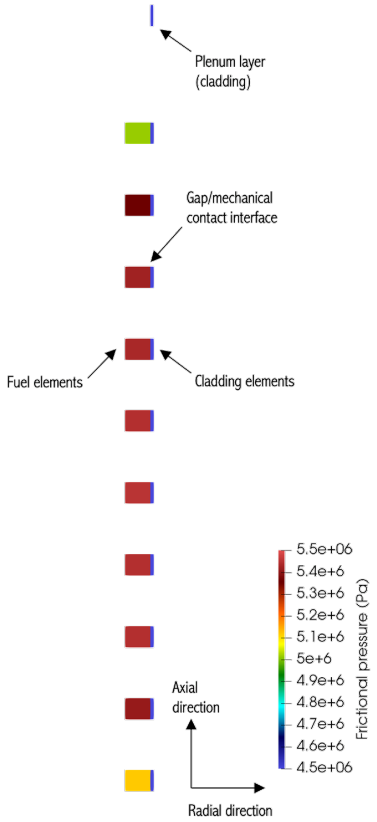
NUCLEAR FUELS & MATERIALS
brenden.heidrich@inl.gov

NSUF Nuclear Science User Facilities

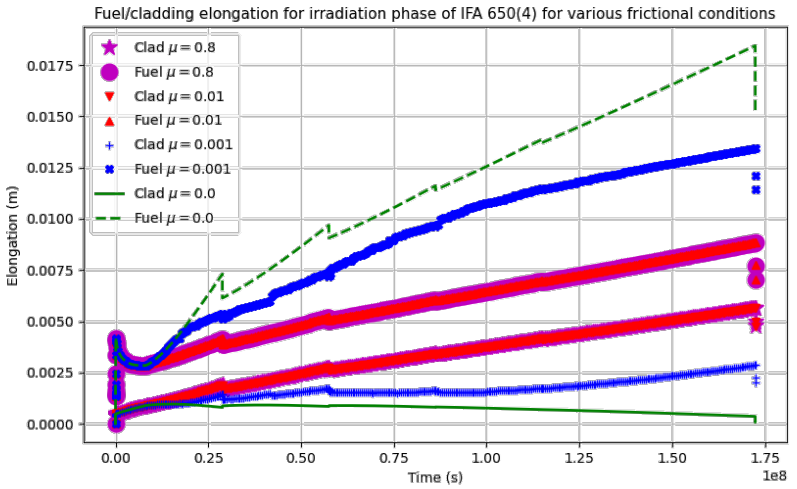
DOE-NE Nuclear Energy Advanced Modeling and Simulation Program

BISON Incorporates Frictional Interaction in Fastest Fuel-rod Thermo-mechanical Simulations

- Fast and accurate nuclear performance modeling allows users to generate massive amounts of physics-based data.
- Frictional interaction between fuel and cladding was recently added to one-dimensional, layered, thermomechanical simulations in the nuclear fuel performance code BISON.
- This new capability facilitates the employment of uncertainty quantification and sensitivity analysis techniques with added accuracy, particularly in the axial mechanics of the cladding material.



Layered, one-dimensional assumption speeds up simulations 20x over two-dimensional geometries.



Influence of friction on fuel/cladding elongation during the irradiation phase of IFA 650 (4). Note: Cladding elongation results exclude the plenum elements.

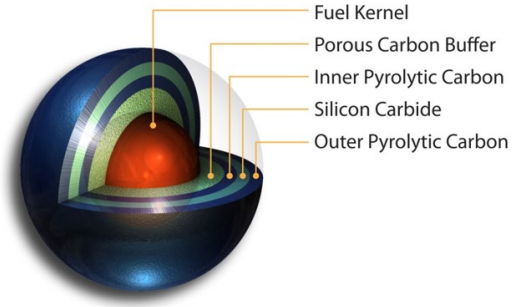
COMPUTATIONAL MECHANICS AND MATERIALS
antonio.martinrecuero@inl.gov, kyle.gamble@inl.gov

Research Highlight

DOE-NE Advanced Reactor Technologies Program

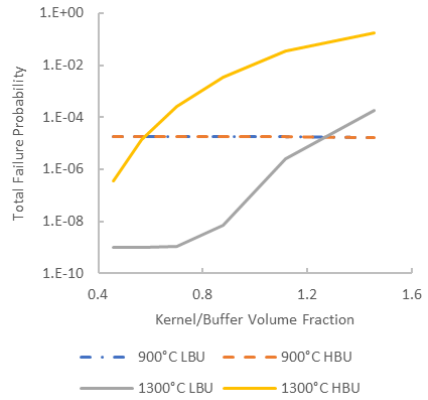
Fuel Performance of a Modified Advanced Gas Reactor Tristructural isotropic (TRISO) Fuel Particle for Low-Burnup Microreactor Applications

- TRISO fuel is currently being considered for high-temperature reactor designs. These designs deviate significantly from the prismatic or pebble bed modular high-temperature gas-cooled reactors that were considered at the outset of the U.S Department of Energy Advanced Gas Reactor (AGR) program.
  - Designs include microreactors with compact core designs that could benefit from increasing the core fissile density beyond that conventionally required.
- Using the AGR-5/6/7 TRISO fuel particle as a baseline reference, the ratio of the kernel volume to the buffer volume was increased while maintaining a constant coated particle diameter to increase the fissile density in the core.
  - Modeling of the modified AGR particle geometry was completed to evaluate the fuel performance as a function of the kernel/buffer volume ratio.
- The results show that there is potential for increasing the kernel diameter while decreasing the buffer layer thickness to increase fuel loading at low target burnups.
- Modifying the TRISO particle geometry with minimal impact to fuel performance will give reactor core designers an additional degree of freedom in the development of microreactors using TRISO fuel.



Typical TRISO-coated fuel particle consisting of a fuel kernel surrounded by four layers.

End-of-irradiation fuel particle failure probabilities at irradiation temperatures of 900°C and 1300°C for low-burnup and high-burnup fuel.



Title: Kernel/Buffer Volume Fraction Margin of the AGR Reference Fuel Particle, INL/RPT-23-71441
Author: W. F. Skerjanc (C620)
Link: osti.gov/servlets/purl/1962863

william.skerjanc@inl.gov

Idaho National Laboratory Featured at Cambridge Energy Research Associates Week

- INL Director John Wagner participated in a net-zero panel during S&P Global Cambridge Energy Research Associates (CERA) Week, March 6–10 in Houston, Texas.
- CERA Week is a gathering of top global industry and energy executives.
- During the panel discussion, Wagner highlighted the advantages of carbon-free advanced nuclear energy technology, alongside INL Senior Advisor of Strategic Programs Steven Aumeier and Wyoming Energy Authority Director of Industrial Development Marcio Paes-Barreto.

John Wagner

Steven Aumeier

- The title of their presentation, “A Regional to Global Strategy for Nuclear Development,” emphasized how advanced nuclear technology holds the key to competing in emerging low-emission industrial product markets.
- INL’s Emerging Markets Analysis Initiative is working with Wyoming, Alaska, and Idaho—states that are early adopters of advanced nuclear deployment to pave a way to a “new frontier” of economic competition.

donna.kempspangler@INL.gov

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- Woolstenhulme, N., Chapman, Daniel, Cordes, Nikolaus, Fleming, Austin, Hill, Connie, Jensen, Colby, Schulthess, J., Ramirez, M, Linton, K., Schappel, Danny, Vasudevamurthy, G.. 2023. "TREAT testing of additively manufactured SiC canisters loaded with high density TRISO fuel for the Transformational Challenge Reactor project." JOURNAL OF NUCLEAR MATERIALS. Vol. 575. https://doi.org/10.1016/j.jnucmat.2022.154204.