INL/MIS-24-76454-Revision-0

December 2023 NS&T Highlights

February 2024

Addison Marie Arave

Changing the World's Energy Future

Idaho National Laboratory

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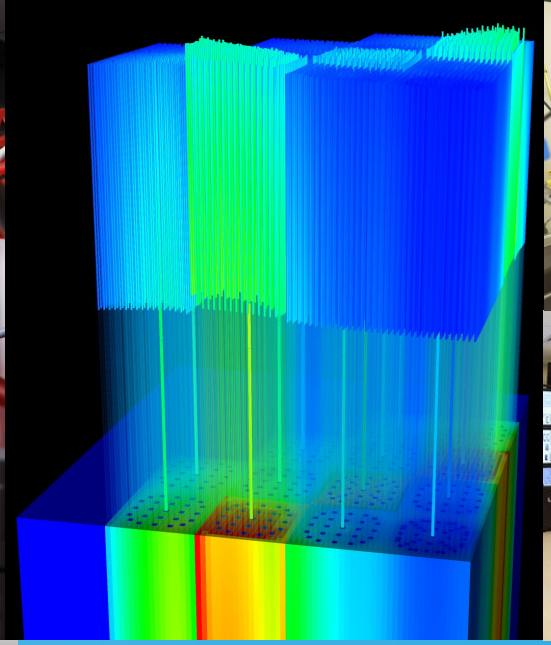
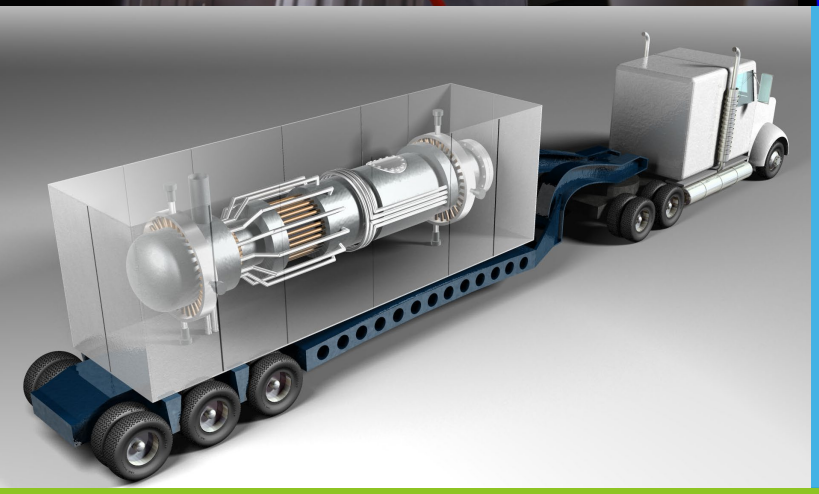
Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517



Nuclear Science & Technology

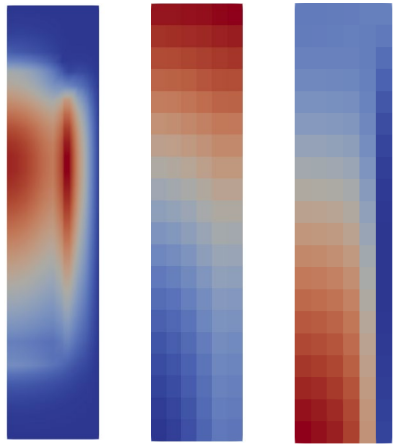
December 2023 Highlights

Idaho National Laboratory

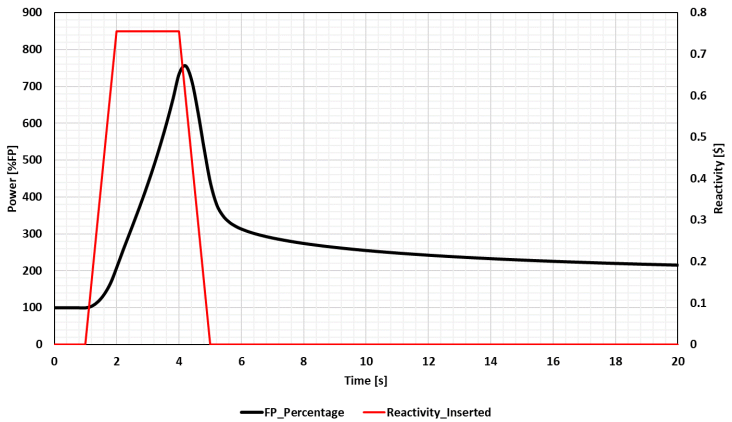
DOE-NE Nuclear Energy Advanced Modeling and Simulation Program and Nuclear Regulatory Commission non-Light Water Reactor Advanced Reactor Funding

INL Hosts Nuclear Regulatory Commission Workshop

- On December 11, 2023, INL hosted a training workshop for the Nuclear Regulatory Commission (NRC) and Argonne National Laboratory (ANL) staff to demonstrate the use of the INL/ANL-developed application, Griffin, for pebble bed reactor (PBR) analysis as part of the High-Temperature gas-cooled Reactor Pebble-bed Module (HTR-PM) reference plant model.
- The workshop strengthened collaboration between the NRC and the INL Nuclear Energy Advanced Modeling and Simulation (NEAMS) team, and it has led to plans for additional workshops for coupled Griffin-Pronghorn System Analysis Module (SAM) calculations in the next calendar year.
- It is expected that the HTR-PM reference plant model will be leveraged to develop the NRC's evaluation model for Xe-100™.



Thermal flux, U235 and Pu239 distributions in the equilibrium core.



Control rod withdrawal transient for the HTR-PM using Griffin.

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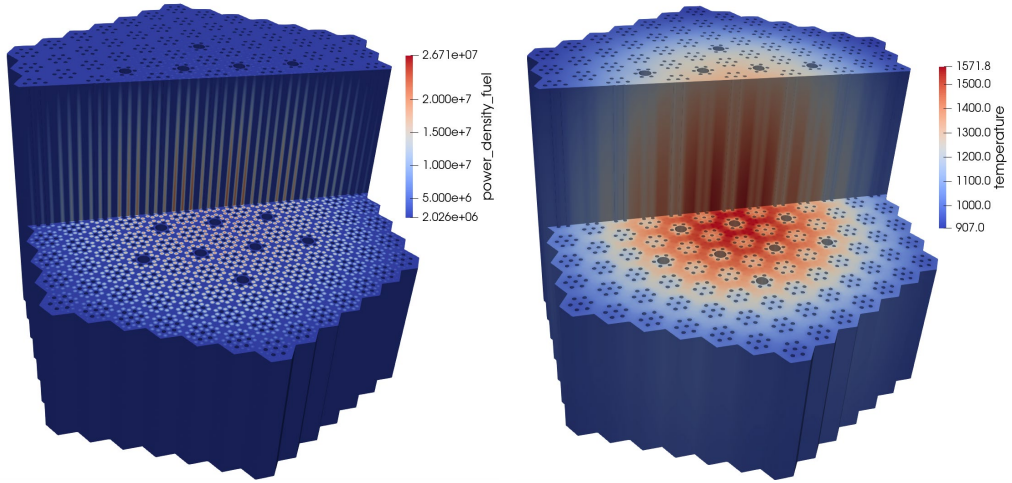
Program Highlight

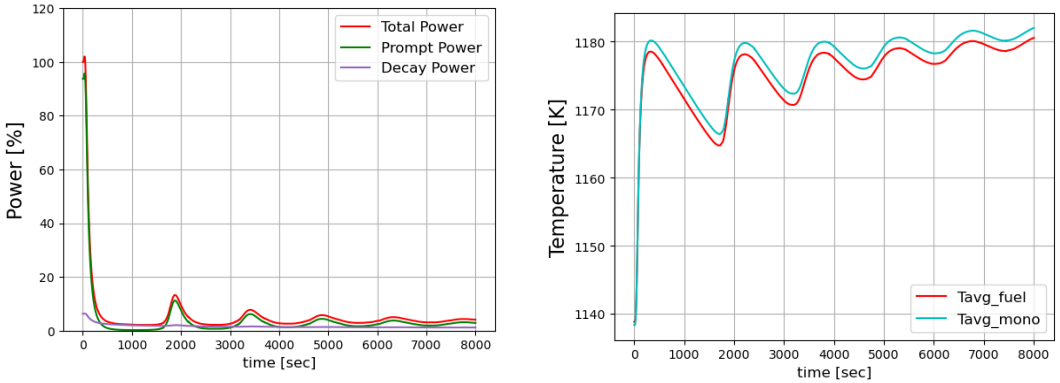
DOE-NE Nuclear Energy Advanced Modeling and Simulation Program and Nuclear Regulatory Commission non-Light Water Reactor Advanced Reactor Funding

Transient Microreactor Model Presented to the NRC

- The monolithic micro reactor reference plant model was presented to the research and operation branches of the United States Nuclear Regulatory Commission (NRC) on December 12, 2023.
- The model couples the MOOSE-based applications Griffin, BISON, and Sockeye to solve fully-heterogeneous discrete ordinates (SN) transport coupled to heat conduction and heat pipe performance.
- Each heat pipe is included explicitly with the Sockeye vapor-only model.
- Model specifications are based on open literature information.
- This engagement helped determine needs for the NRC reference plant.
- Future work will leverage this reference plant model to develop the NRC's evaluation model for eVinci™.



SN Transport Pin Power and Temperature distribution at steady state.



Loss of heat sink transient (based on initial diffusion calculations, SN transport under deployment).

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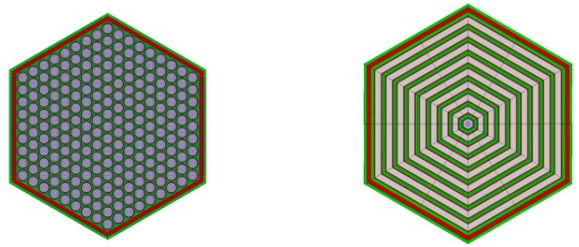
Program Highlight

DOE-NE Nuclear Energy Advanced Modeling and Simulation Program and Nuclear Regulatory Commission non-Light Water Reactor Advanced Reactor Funding

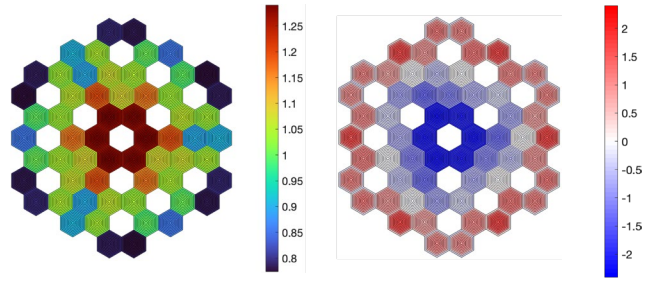
Novel Neutronics Analysis Method Developed for Sodium Fast Reactors

- INL Griffin Multiphysics team developed the ring-heterogeneous approach to modeling Sodium Fast Reactors (SFR).
- This approach relies on the Griffin discrete ordinates (SN) transport solver with mesh displacement.
- The treatment
  - explicitly allows the deformation of each reactor component (fuel, HT9, B_4C) and density changes in the Na coolant.
  - promotes efficient analysis and improved power distributions.
  - enables an intermediate resolution for multiphysics modeling of SFRs by allowing users to capture important SFR thermal expansion feedback effects more accurately.
- The method is being adopted in the Nuclear Regulatory Commission's SFR reference plant model, which will be the basis for their evaluation model for Natrium™.



In the ring-heterogeneous approach the assembly materials are modeled as concentric bands.

3D core	MC	Griffin RH
Eigenvalue	1.03288 (± 1)	1.03368 (80)



3D core power comparisons between Monte Carlo and Griffin. Axially-integrated ring-wise fission reaction rates of MC (left) and Griffin errors (%) with 9 energy groups.

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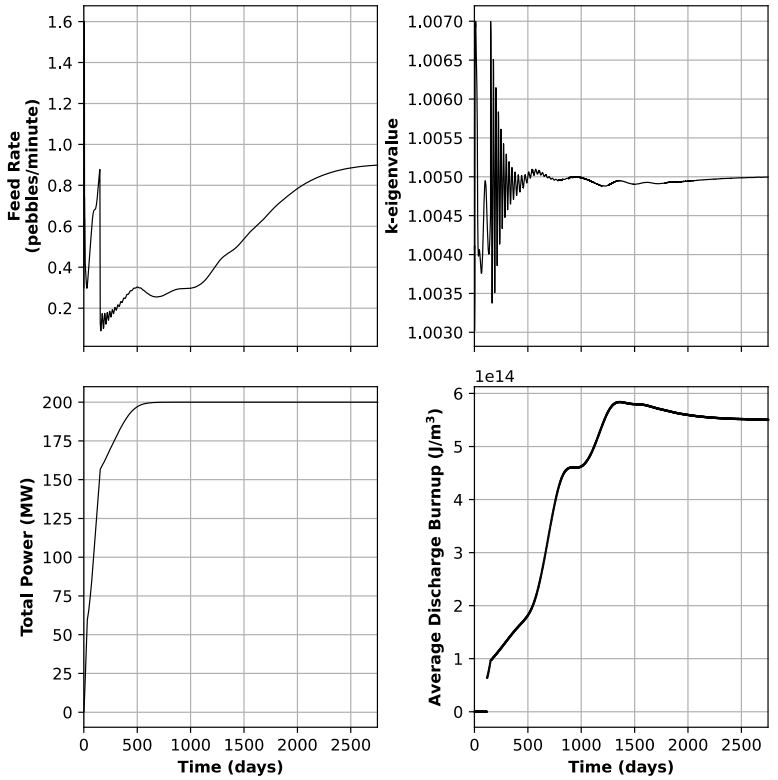
DOE-NE Nuclear Energy Advance Modelling and Simulation Program

Running-In Phase of Pebble-Bed Reactor Operation Simulated Using Griffin

- Pebble-Bed Reactors (PBRs) are initially filled with graphite pebbles and brought to criticality as the initial graphite pebbles exit the reactor and are replaced with fuel pebbles.
- Reactor power is increased over time as more fuel is added and graphite pebbles are removed, with fuel burnup increasing as power is produced.
- PBRs are fueled continuously, and eventually, a steady state condition is reached where the average burnup of the fuel is constant, and the reactor operates continuously at rated power.
- Simulating the running-in phase is critical economically and operationally.
  - Reaching the rated operating power levels as quickly as allowable is an economic imperative.
  - Safety related calculations depend on accurately simulating core configuration during this phase where the core changes with time.



Important quantities plotted for the first 2,750 days of simulated PBR operation.

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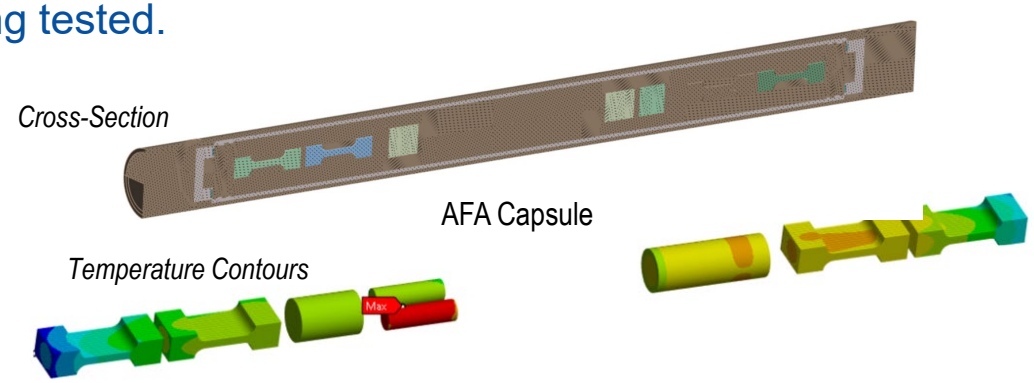
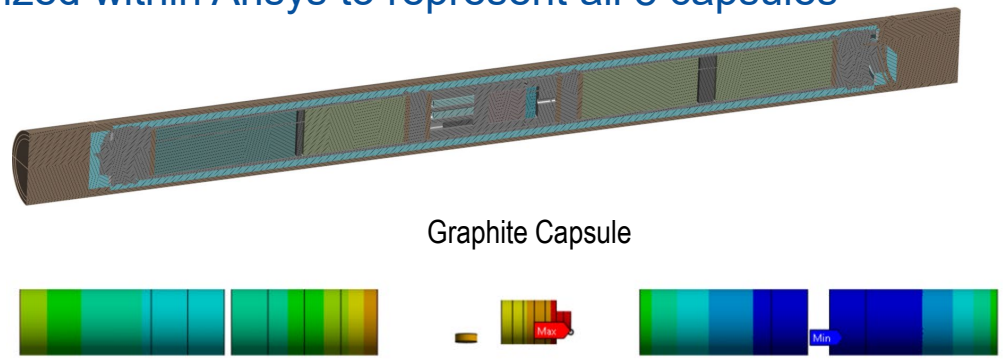
Research Highlight

DOE-NE Nuclear Science User Facilities Program and UK National Nuclear User Facility (NNUF) Program

Heat Transfer Models Support Advanced Test Reactor Non-Fueled Materials Capsule Experiments

- The neutron irradiation as a function of temperature experiment (NIFT-E) is designed to use the Nuclear Science User Facilities' standardized capsule for a drop-in experiment in the Advanced Test Reactor "B-7" test location to irradiate graphite, alumina forming austenitic (AFA) stainless steel (SS), miscellaneous ferritic/martensitic steels, Grade 91 steel, high entropy alloys (HEA), and hetero nano-composite specimens using eight irradiation capsules.
- Post irradiation examination of the samples will capture the change in material microstructure, mechanical properties, and corrosion behavior of graphite, AFA stainless steel, and various miscellaneous metallic alloys, as a function of neutron irradiation dose and irradiation temperature.
- The specimen temperature targets were optimized by parametric studies of the capsule gap dimensions and gas mixtures.
- Experiment capsule heat transfer models incorporated a single model for the AFA and Graphite capsules, while the fixture outer diameters, gas mixtures, and heat generation rates were parameterized within Ansys to represent all 8 capsules being tested.





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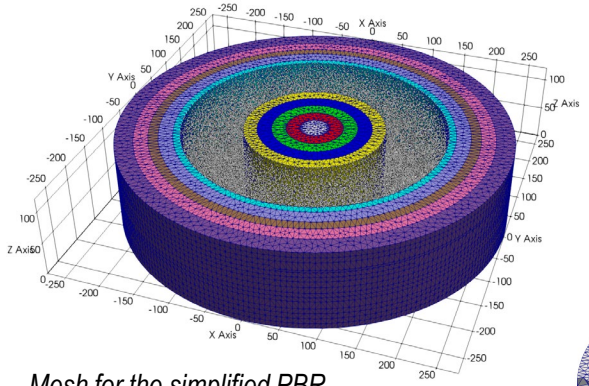
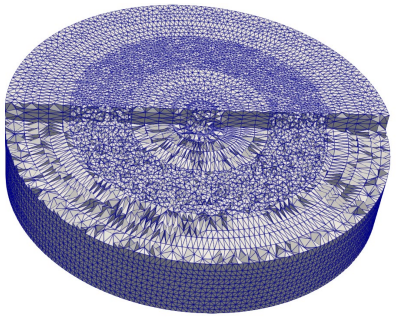
DOE-NE Nuclear Energy Advance Modelling and Simulation Program

Pebble Tracking Transport is Accelerated for Pebble Bed Reactor Analysis

- Pebble tracking transport (PTT) is a novel approach for tracking individual pebbles in Pebble Bed Reactor (PBR) analysis.
- It allows the explicit representation of the pebbles and their effects on the neutron flux and related fields, e.g., power, absorption rate.
- It provides reference solutions to verify routine streamline-based calculations or to conduct special studies, e.g., near-wall effects.

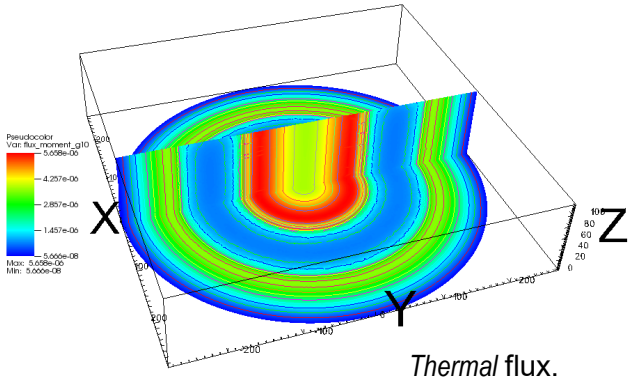


Mesh for the simplified PBR.



Mesh with some coarse elements removed.

- Coarse Mesh Finite Difference (CMFD) acceleration has been added to PTT.
- A simplified PBR benchmark (shown in the right figures) with 41,048 pebbles can be computed in 18 min on 2 Sawtooth nodes (96 processors) improving performance by a factor of 4x.
- This approach lays a solid foundation for future high-fidelity PBR analysis with Griffin.



Thermal flux.

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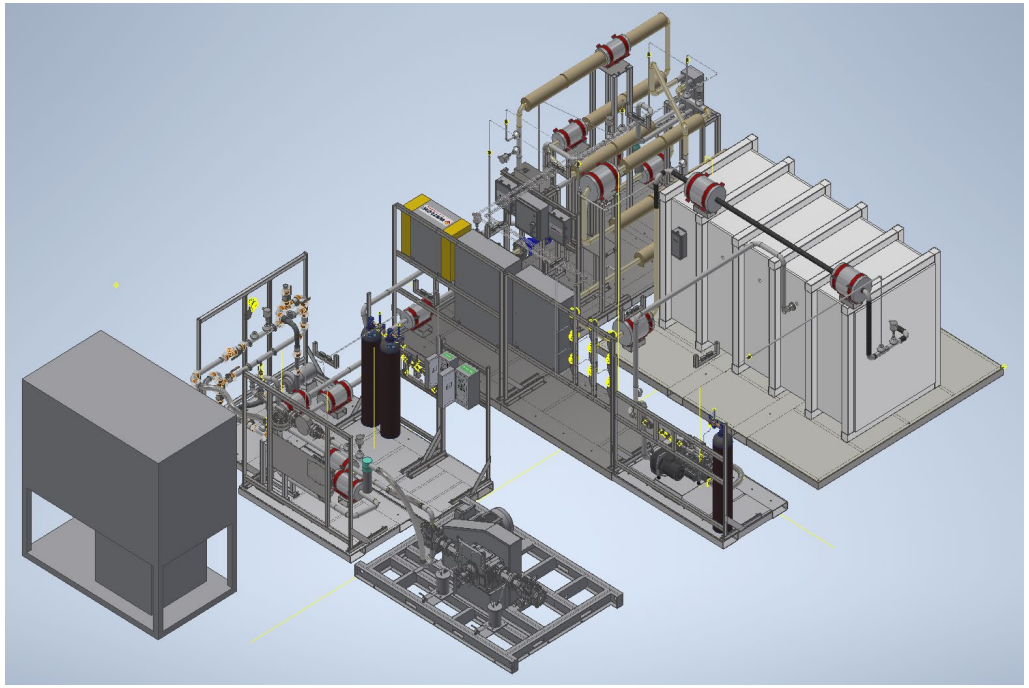
DOE-NE Microreactor Program

Final Design Completed for Helium Component Testing Out-of-Pile Research Facility

- High temperature gas cooled reactor (HTGR) design concepts require vigorous testing for components to be selected. Limited access to test facilities for operation up to 800°C and 8MPa within the United States limits the ability to accomplish technology maturation for these reactor concepts.
- The HElium Component Testing Out-of-pile Research, or HECTOR facility is anticipated to provide with the infrastructure needed to perform component test experiments at a pressure, temperature, and mass flow rate up to 8 MPa, 800°C, and 0.15 kg/s.
- This experimental facility will enable testing of heat exchangers, valves, compressors, and more to reduce their performance uncertainty.
- The final design of the HECTOR facility has been completed, and the next step is to establish a construction contract to build the HECTOR loop.



Model overview of the proposed design of the HECTOR facility.

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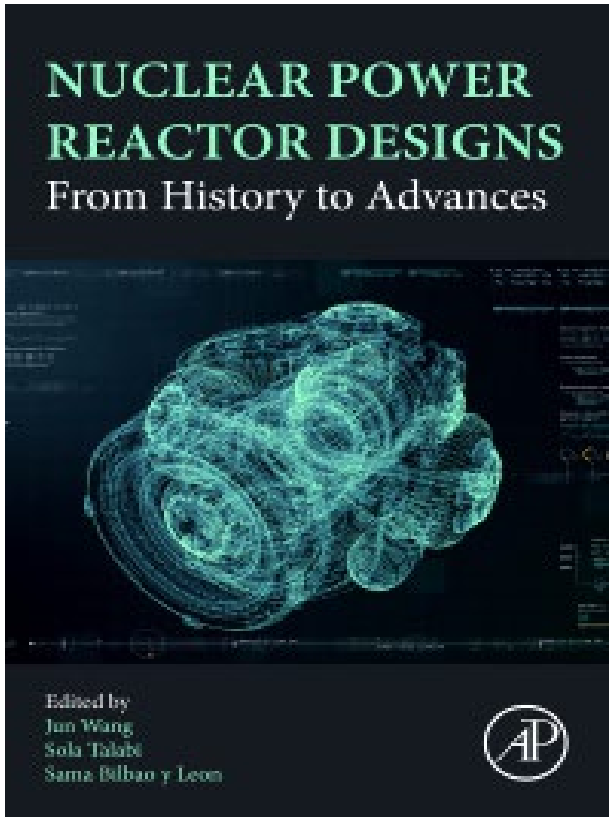
DOE-NE Advanced Reactor Technology – Small Modular Reactor Program

Researchers Contributed to New Book on Nuclear Power Reactor Designs From History to Advances

- Researchers from the Nuclear Science and Technology directorate contributed a chapter on small modular reactors (SMR) to a new book on nuclear power reactor designs.
- SMRs are defined as nuclear reactors with a power output of less than 300 MWe. They are not a new concept, but they do represent a new vision for an older concept.
- The chapter gives a general overview of the recent advancements, understanding of how nuclear designs have evolved, and how they will continue to develop in the future.
- It consists of two major sections.
  - The first is a detailed summary of proposed SMR designs focusing on those that are the furthest along in their development, but it also includes some information about the wide variety of proposed designs that require significant research and development.
  - The second part discusses the remaining challenges to the adoption of SMRs as a major energy source.



This book can be purchased here.

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RELAP5-3D Initiative

INL Hosts 2023 International RELAP5 User Group Training and Seminar

- Eighty registrants, including 69 in-person attendees, from 20 organizations participated in the week-long event, which offered 2.5 days of beginning RELAP5-3D training. The event was followed by the International RELAP5 User Group (IRUG) technical seminar and business meeting.
- The event was the first in-person meeting for IRUG since 2019.
- Nineteen topics were presented during the beginner training followed by an optional certification exam.
- Thirty-three topics were presented during the technical seminar and business meeting.
- An associated networking event featured one of the original Reactor Excursion and Leak Analysis Program (RELAP) developers, Victor Ransom, as well as NS&T Chief Scientist, Simon Pimblott.

RELAP5-3D Beginner Training.

IRUG Networking Event.

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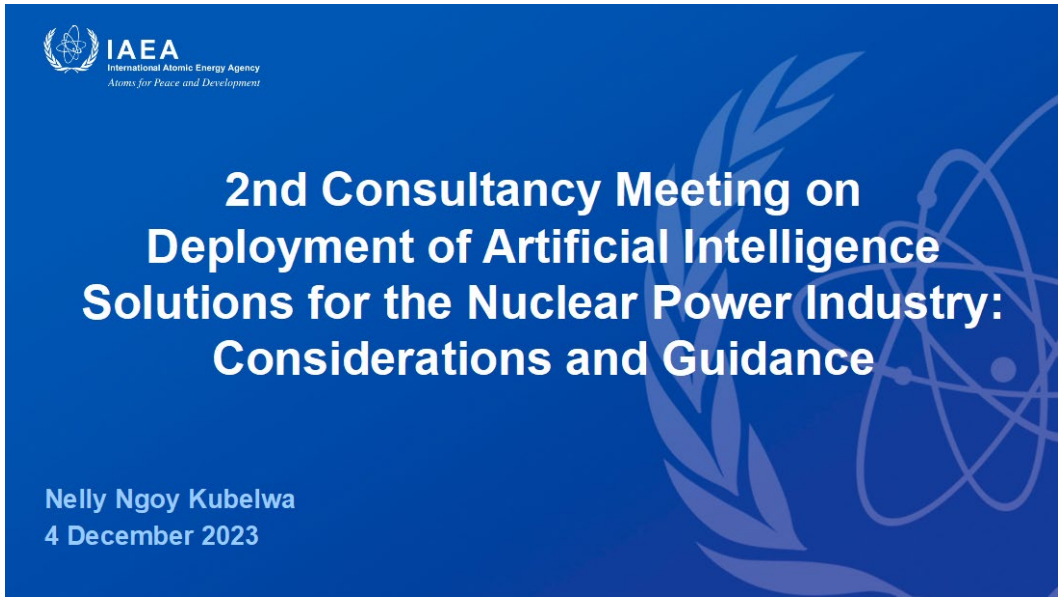
DOE-NE Light Water Reactor Sustainability Program

Vivek Agarwal Chairs the International Atomic Energy Agency Publication Meeting on Artificial Intelligence

- Dr. Vivek Agarwal chaired the International Atomic Energy Agency's (IAEA) publication meeting titled "Deployment of Artificial Intelligence Applications for the Nuclear Power Industry: Consideration and Guidance" in Vienna, Austria from December 4–8, 2023.
- The purpose of the meeting was to draft and address reviewers' comments on an IAEA publication describing the benefits of deploying Artificial Intelligence to the nuclear industry, covering its lifecycle, data, and implementation strategies.
- Fifteen participants from different member states took part in the hybrid meeting.



Research Highlight

Electric Power Research Institute

Build-to-Replace Paradigm Examined With Respect to Operations and Maintenance for Advanced Reactors

- The Build-to-Replace project questioned and re-examined the underlying assumptions of the operations and maintenance (O&M) approaches and practices of advanced reactors (AR).
- The project asked whether more frequent and predictable replacement of assets would result in improved O&M costs by avoiding costs associated with longer service life.
- The INL RAVEN code was employed to analyze the economic impact of a Build-to-Replace strategy for the various scenarios.
- It was shown that the Build-to-Replace process does not unilaterally apply to every scenario but can create unexpected benefits depending on the specific scenario considered.
- Work was directed by the Electric Power Research Institute in collaboration with INL and the Massachusetts Institute of Technology.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

INL Idaho National Laboratory

MIT

RAVEN

Title: Build-to-Replace: Methodology Report
Authors: A. Sowder et al (EPRI), K. Shirvan (MIT), D. Mandelli (INL)
Link: https://www.epri.com/research/products/000000003002026493

NUCLEAR SAFETY & REGULATORY RESEARCH | C230 Risk Reliability and Resilience Sciences
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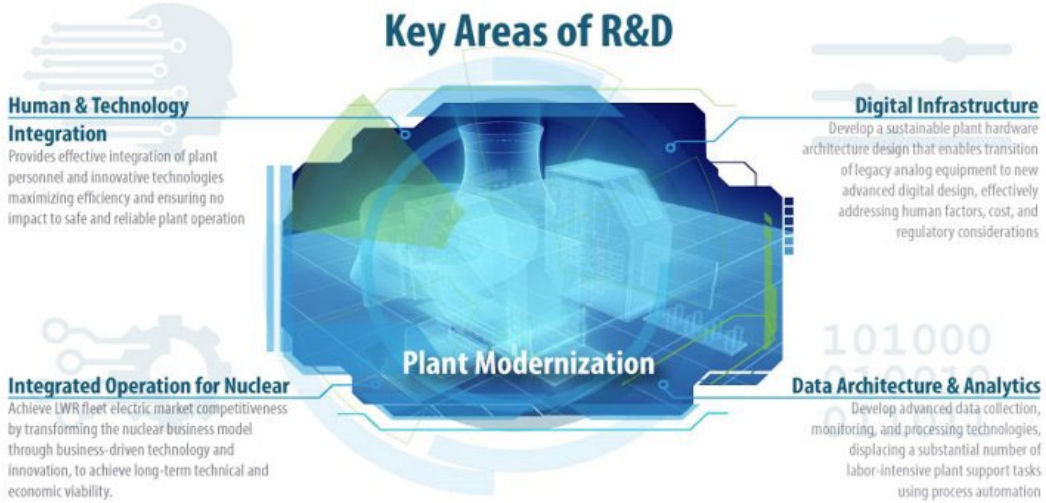
DOE-NE Light Water Reactor Sustainability Program

Light Water Reactor Sustainability Program Engages with Nuclear Industry Stakeholders

- The Light Water Reactor Sustainability Program's (LWRS) Plant Modernization Pathway held a virtual stakeholder engagement meeting on December 5–7, 2023, which was attended by 300 participants from the Department of Energy, industry, utilities, the Nuclear Regulatory Commission, academia, and the national laboratories.
- Plant Modernization Pathway research focuses on building a sustainable business model for the United States nuclear industry, ensuring continued safe, reliable operation at a cost-competitive level.
- This meeting provided an overview of research results in the areas of digital infrastructure, data architecture and analytics, human and technology integration, and integrated operation for nuclear.
- The meeting presentations are available here.



Areas of focus for the LWRS Plant Modernization Pathway stakeholder engagement meeting.

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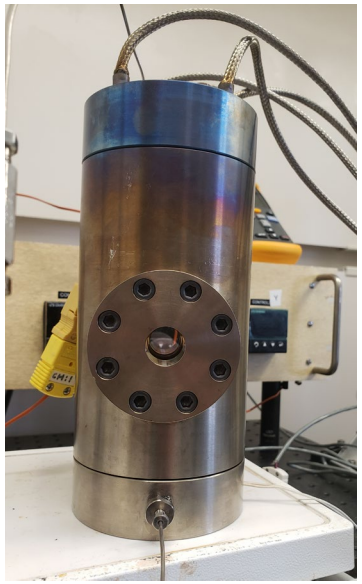
LWRS LIGHT WATER REACTOR SUSTAINABILITY

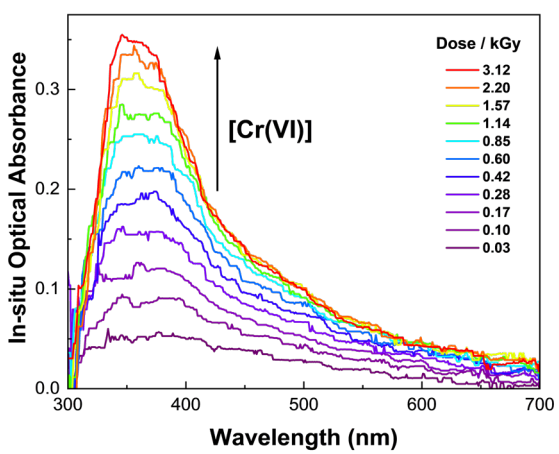
INL Laboratory Directed Research and Development

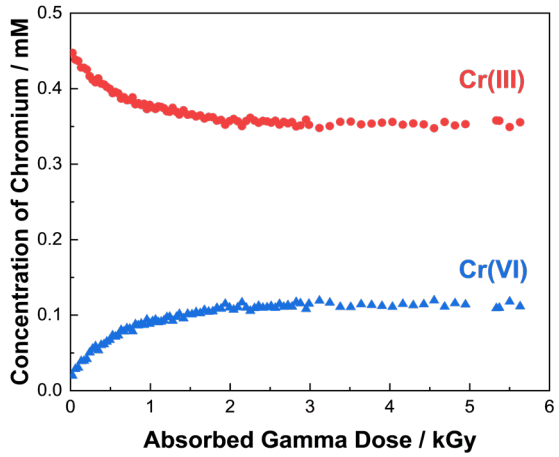
First-of-a-Kind In-Situ Measurements Reveal Radiation-Induced Chromium Redox Chemistry

- The longevity of nuclear reactors is impacted by the presence of chromium ions in the primary coolant as a result of corrosion of reactor components.
- Use of a high temperature titanium vessel equipped with integrated fiber optics was employed for the in-situ measurement of radiation-induced changes in the oxidation state distribution of Cr in aqueous solution (pH 2–4) as a function of temperature (≤ 195°C).
- This work is an important step in understanding the impact and behavior of chromium in nuclear reactor operations.



Custom-built high temperature cell for gamma irradiations





The radiation-induced growth of Cr(VI) from a solution of Cr(III) as determined by optical spectroscopy.

Title: High Temperature Gamma Radiation-Induced Chromium Redox Chemistry via in situ Spectroscopic Measurements
Authors: J. Conrad, R. Fox, E. Danaher, and G. Horne
Journal: Physical Chemistry Chemical Physics
Link: doi.org/10.1039/D3CP05296F

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DOE-NE Spent Fuel and Waste Disposition Program

INL Staff from Fuel Cycle Science Accompanies Department of Energy on Tour of TRISO Production Laboratory

- INL Spent Fuel Analysts Robby Joseph and Gordon Petersen joined Jorge Narvaez from DOE on a tour of the Ultra-Safe Nuclear Corporation (USNC) pilot TRi-structural ISOtropic particle fuel (TRISO) manufacturing facility in Oak Ridge, TN on December 14.
- USNC utilizes TRISO particles in their Fully Ceramic Micro-encapsulated (FCM®) fuel. This unique fuel has unique qualities that are estimated to aid in long-term disposition of the spent nuclear fuel
- INL is aiding the DOE Nuclear Energy Spent Fuel and Waste Disposition Program in evaluating the feasibility of management of advanced reactor fuel forms.

Left to right: Jorge Narvaez, Robby Joseph, Gordon Petersen, Bret van den Akker (USNC).

FUEL CYCLE SCIENCE & TECHNOLOGY | USED FUEL MANAGEMENT
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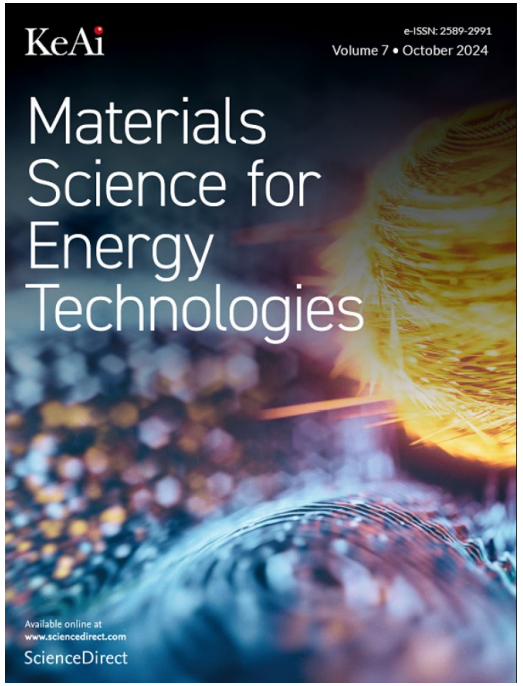
DOE Critical Materials Institute

Elsevier Publishing Identifies NS&T Publication as Supportive of United Nation's Sustainable Development Goals

- Elsevier Publishing identified an INL publication as supportive of two of the United Nation's Sustainable Development Goals (SDG's).
- The publication, "One Step Manufacturing Process for Neodymium Iron (Magnet Grade) Master Alloy" was linked to:
  - SDG 7: Ensure access to affordable, reliable, sustainable and modern energy for all and
  - SDG 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
- The publication describes a novel electrochemical-based manufacturing process to prepare a neodymium iron alloy from a mixed oxide precursor. The alloy is required for the fabrication of neo magnets, which are widely used in wind turbines, computer hard disk drives and consumer electronics.



Title: One Step Manufacturing Process for Neodymium Iron (Magnet Grade) Master Alloy
Authors: P. Tripathy, K. Mondal, A. Khanolkar
Journal: Materials Science for Energy Technologies
Link: https://doi.org/10.1016/j.mset.2021.07.001

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Dr. Derek Gaston Selected as Senior Technical Advisor for the Assistant Secretary for Nuclear Energy

- Chief Computational Scientist Dr. Derek Gaston of the Advanced Scientific Computing division at Idaho National Laboratory, has been selected as Senior Technical Advisor for the Assistant Secretary for Nuclear Energy, Dr. Katy Huff and the Deputy Assistant Secretary for Nuclear Energy, Dr. Mike Goff, at the Department of Energy.
- This prestigious assignment will require relocation to Washington D.C. where Gaston will work alongside policymakers to support deployment of advanced nuclear technology.
- Gaston has been part of Idaho National Laboratory for over 15 years and is best known for his work spearheading the development of MOOSE.
- For the last 4 years, he has also been Deputy National Technical Director for the Nuclear Energy Advanced Modeling and Simulation program.

Chief Computational Scientist
Dr. Derek Gaston.

ADVANCED SCIENTIFIC COMPUTING
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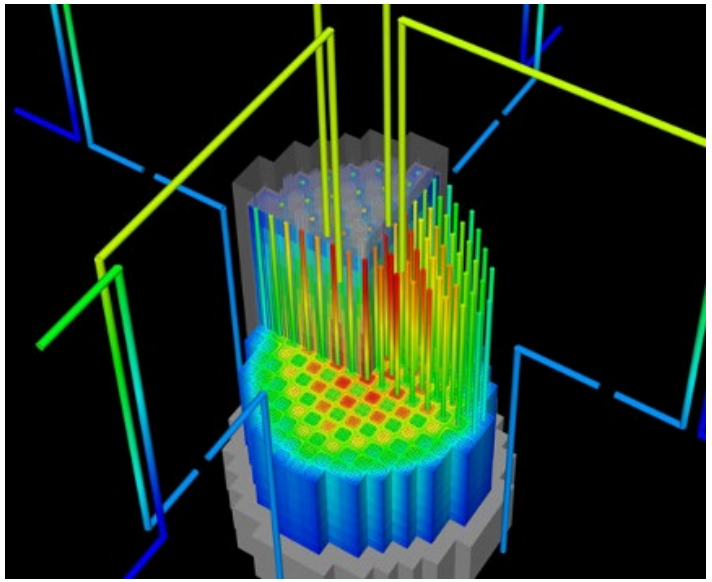
DOE-NE Nuclear Energy Advanced Modeling and Simulation Program

Inaugural MOOSE International Workshop Announced

- The Multiphysics Modeling for Energy and Environmental Applications MOOSE International Workshop will be a three to five-day technical conference and workshop and is slated for March 2025 with exact dates and location to be announced in March 2024.
- Internal and external steering committees have been formed, and a scoping and interest survey was released, additional input welcome here.
- Planned topics include:
  - Concurrent technical sessions on all aspects of multiphysics modeling and simulation, as related to energy and the environment.
  - Training opportunities for MOOSE and MOOSE-based codes.
  - Panel sessions to obtain feedback on current and future development directions.



AP-1000 simulation created using MOOSE-based applications.

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DOE-NE Gateway for Accelerated Innovation in Nuclear Initiative

Coal Communities Gain Insight at First Coal to Nuclear Workshop

- Gateway for Accelerated Innovation in Nuclear (GAIN) led a workshop aimed at coal to nuclear conversions.
- Titled “Adding Nuclear to the Mix,” the workshop was held November 14–15, 2023, in Morgantown, West Virginia.
- GAIN partnered with Nuclear Energy Institute, Electric Power Research Institute, West Virginia University and Good Energy Collective to sponsor the gathering that focused on exploring the expansion and integration of nuclear power alongside existing energy resources.
- About 100 people representing industry, local and federal government, and academia were in attendance.

GAIN Director Christine King (left) Nuclear Institute Alliance Eric Colton (right).

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DOE-OCED National Reactor Innovation Center - Molten Salt Thermophysical Examination Capability

Multidisciplinary Effort Brings MSTEC Shielded Glovebox to INL Fuel Conditioning Facility

- Engineers, operators, scientists, and glovebox experts performed factory acceptance tests on the MSTEC shielded glovebox at Extract Technologies in Wisconsin.
- Dismantling and shipment of the 82-ton MSTEC structure began January 17, 2024.
- With the construction contract already approved, installation of MSTEC into the Fuel Conditioning Facility (FCF) also began in January.
- MSTEC is a transuranic glovebox also designed to handle irradiated materials.
- Furnaces and characterization equipment will be installed in MSTEC, making it a state-of-the-art testbed for salt synthesis, chemistry, and lab scale fuel cycle studies.

The shielded side of the MSTEC glovebox with INL staff during the factory acceptance testing.

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DOE-NE Nuclear Science User Facilities

Nuclear Science User Facilities Program Emphasized at American Nuclear Society MiNES Meeting

- Nuclear Science User Facilities (NSUF) leadership participated in the recent American Nuclear Society sponsored Materials in Nuclear Energy Systems (MiNES) meeting.
- NSUF was well-represented with multiple university and laboratory partners attending and participating in the meeting.
- There were four parallel technical tracks including many engaging presentations highlighting NSUF-related work.
- The NSUF director, Brenden Heidrich, had the opportunity to deliver a comprehensive overview of the program and emphasized opportunities available for researchers.
- The NSUF US/UK collaborative ATR irradiation project, NIFT-E, was presented by technical lead, Simon Pimblott.

NSUF director highlighting the NSUF program and capabilities.

NSUF partner, Westinghouse, advertising NSUF capabilities during the exhibit.

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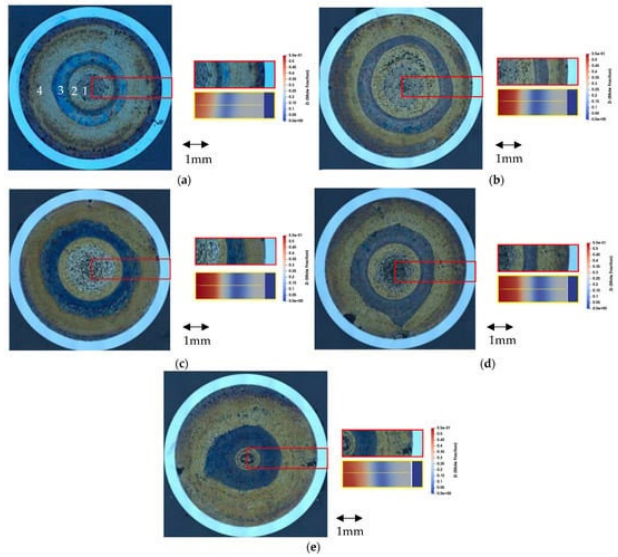
NSUF Nuclear Science User Facilities

DOE-NE Nuclear Science User Facilities

Researchers Capture More Accurate Microstructure Representation of Uranium-Zirconium Specimens

- Metallic fuels have seen increased interest for future sodium fast reactors due to their high thermal conductivity and burnup potential; however, one drawback to typical metallic fuels is zirconium redistribution.
- The BISON tool that allows researchers to model the complex coupled thermo-mechanical behavior and nuclear properties of the fuel.
- This project utilized two fuel pins from EBR-II experiment X441 to optimize various model parameters, before implementing the final model for seven fuel pins with differing characteristics.
- To properly evaluate the BISON simulations, the results are compared to PIE metallography data for each fuel pin, to ensure the zirconium redistribution is properly reflected in the simulation results.
- Six out of seven analyzed fuel pins demonstrated good agreement between the metallography images and BISON results, showing alignment of the Zr-rich, Zr-depleted, and moderately Zr-enriched zones at various axial heights along the fuel pins.



Metallography images with BISON comparisons.

Title: Comparison of Zirconium Redistribution in BISON EBR-II Models Using FIPD and IMIS Databases with Experimental Post Irradiation Examination
Authors: K. Paaren, S. Christian, L. Capriotti, A. Aitkaliyeva, D. Porter (INL).
Journal: Energies
Link: doi.org/10.3390/en16196817

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DOE-NE Advanced Fuels Campaign

Advanced Fuels Campaign Hosts the French Alternative Energies and Atomic Energy Commission (CEA)

- The Advanced Fuels Campaign hosted participants from the French Alternative Energies and Atomic Energy Commission (CEA) for the Working Group 3: Advanced Fuels and Materials Meeting, December 6–11, 2023.
- This Working Group is outlined in the Bilateral Cooperation Agreement between the U.S. Department of Energy and CEA.
- The collaboration is part of the foundation for a recently elevated cooperation on nuclear energy being proposed at the administration-to-administration level (the so-called ‘Macron Roadmap’).
- Technical teams from CEA-Cadarache/CEA-Saclay and Idaho National Laboratory/Los Alamos National Laboratory meet annually to discuss the status of ongoing joint activities and to propose future activities.

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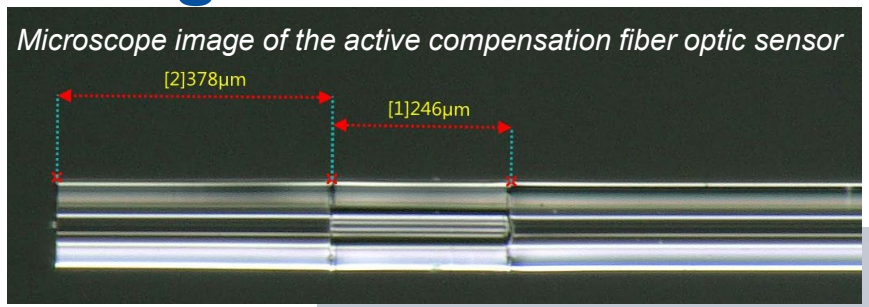
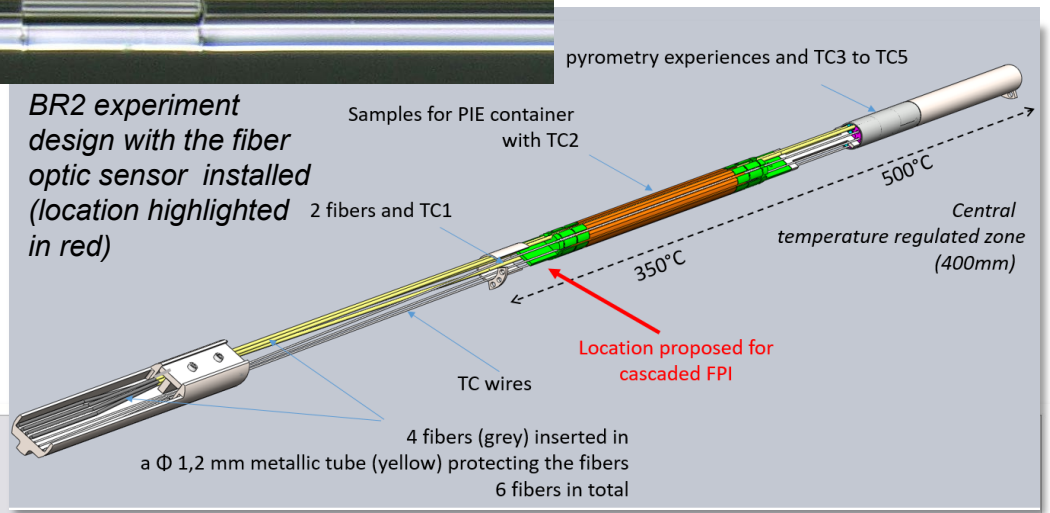
DOE-NE Advanced Sensor and Instrumentation Program

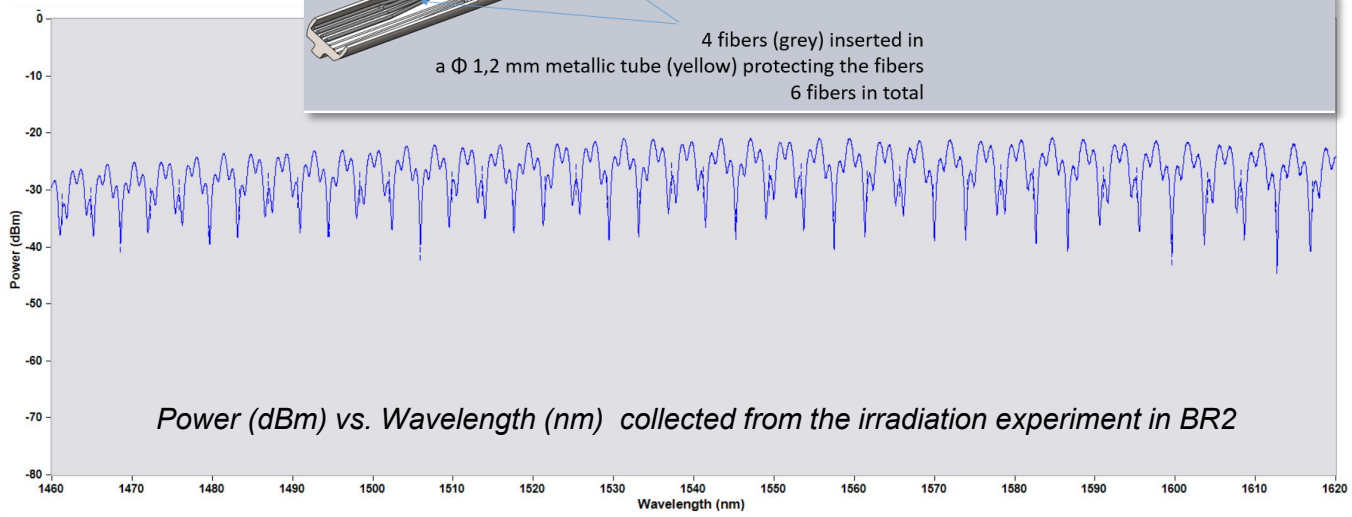
International Collaboration Irradiates Optical Fiber-based Sensors with Active Compensation for Degradation Characterization

- The INL developed and fabricated optical fiber-based sensor with active compensation technology utilizes cascaded Fabry-Perot cavities to independently measure radiation induced compaction and index of refraction changes.
- Radiation induced compaction and index of refraction changes are primarily responsible for the fiber optic sensor drift experienced during high neutron irradiations.
- The irradiation of this sensor began in the Belgium Reactor (BR2) in collaboration with the French Atomic Energy Commission (CEA).
- The results from this experiment have provided data to better understand the fundamental optical behavior of optical fiber-based sensors under high irradiation.



Microscope image of the active compensation fiber optic sensor





Power (dBm) vs. Wavelength (nm) collected from the irradiation experiment in BR2

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