INL/MIS-20-58812-Revision-0

NS&T Highlights May 2020

Joel Newman Hiller

June 2020

The INL is a U.S. Department of Energy National Laboratory
operated by Battelle Energy Alliance

INL/MIS-20-58812-Revision-0

NS&T Highlights May 2020

Joel Newman Hiller

June 2020

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy

Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Nuclear Science & Technology

May 2020 Highlights

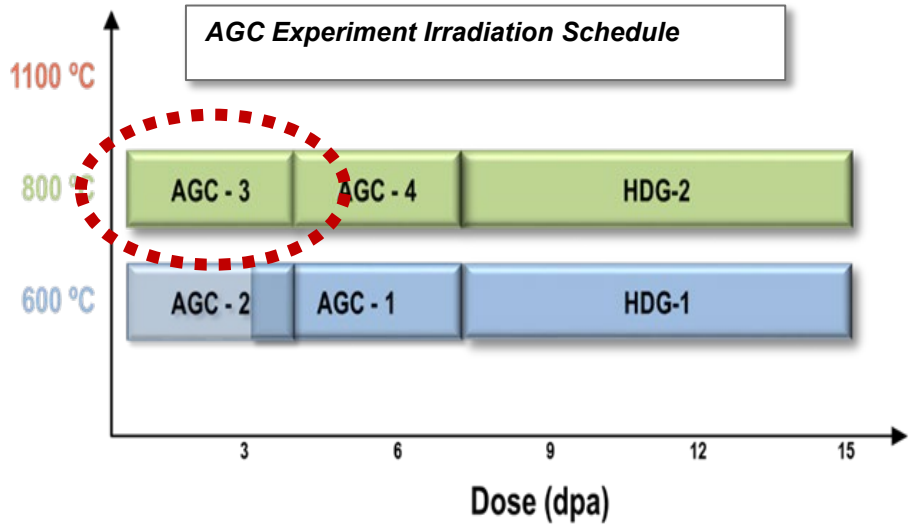
www.inl.gov

Idaho National Laboratory

Idaho National Laboratory

Significant Graphite Creep Experiment Completed, Promoting Advanced Reactor Development

- The Department of Energy Advanced Reactor Technologies (ART) graphite R&D program is conducting the largest graphite irradiation creep experiment in the world to support advanced high-temperature reactor (HTR) designs.
- The experiment consists of irradiating thousands of graphite specimens at different temperatures, machined from nuclear graphite grades currently under consideration from commercial HTR designers.
- This test was the first capsule irradiated at 800°C (3.7 displacements per atom max. dose).



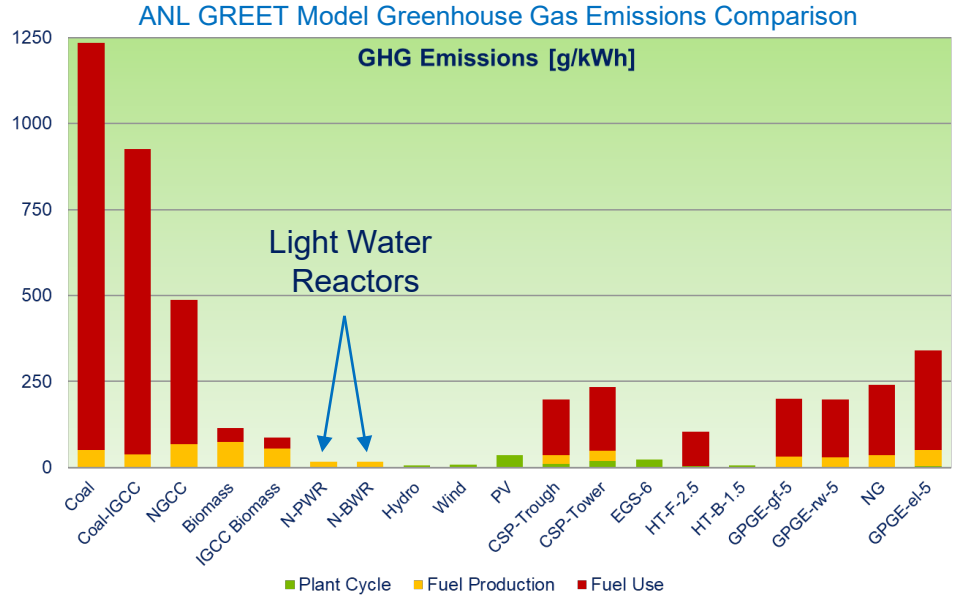
- Data from AGC will eventually provide one of the largest databases of irradiation-induced physical, material property, and creep measurements as a function of dose, grade type, and grade density.
- Critical data on the irradiation creep rate will be available for a variety of nuclear grades currently of interest to the HTR community, providing information on long-term safety of graphite reactor components.

For more information:
william.windes@inl.gov

Idaho National Laboratory

New Report Shows Justification for Nuclear as Clean Energy

- Researchers for the Light Water Reactor Sustainability (LWRS) program completed the report, “Accelerating Decarbonization – Clean Energy Credits for the Production of Low Carbon Hydrogen, Steel, and Ammonia using Nuclear Energy.”
- The report addresses current markets based on:
  - Federal and state clean energy regulations
  - Drivers to produce fuels and other U.S. commodities using nuclear energy.
- Quantifies benefits and market credits that could be available to nuclear energy, such as:
  - EPA Renewable Fuel Standards; Renewable Energy Credits; state standards; other emerging national movement toward zero emissions credits.
- Life-cycle greenhouse gas emission assessments show nuclear as comparable to renewable energy.
- Funding source: DOE-NE's LWRS.



LWRS LIGHT WATER REACTOR SUSTAINABILITY

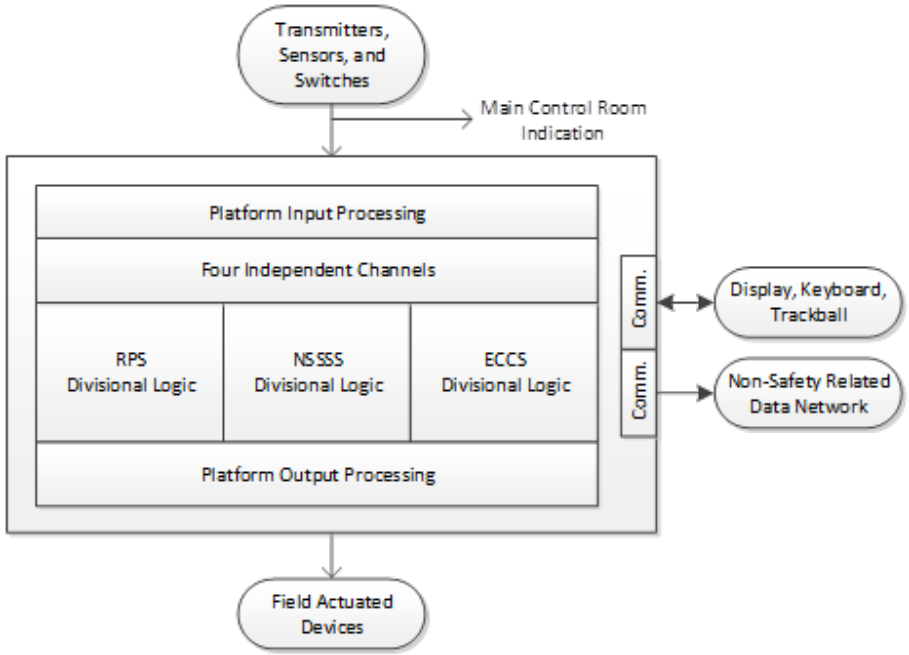
For more information:
richard.boadrman@inl.gov

Idaho National Laboratory

Light Water Reactor Sustainability Program Completes Design and Requirements for Safety System Upgrades

- Light Water Reactor Sustainability Program researchers collaborated with industry to complete a conceptual design and requirements to support upgrades of safety-related Instrumentation and Control Systems at US nuclear power plants.
  - Researchers developed safety system digital upgrade functional requirements that enable improved safety and reliability while reducing operating costs.
  - The team developed a License Amendment Request framework document that conforms to the NRC's alternate approval process.
- Research results will be made available to industry to promote similar upgrades.

Simplified Digital Plant Protection System Architecture



Simplified digital architecture reduces part counts by almost 75% and significantly reduces safety system costs

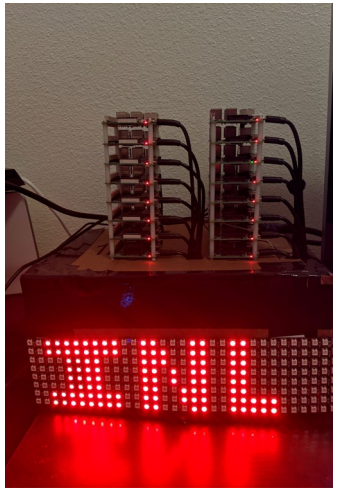
For more information:
paul.hunton@inl.gov

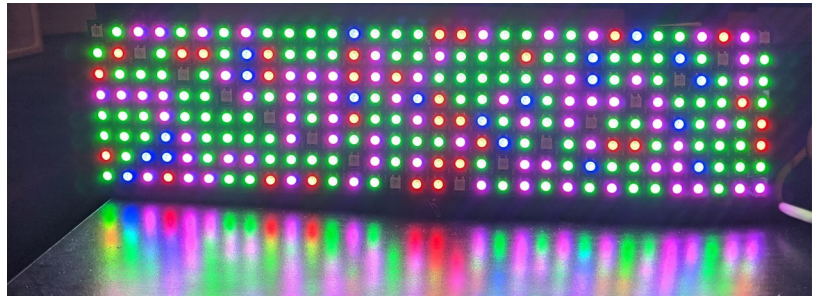
LWRS LIGHT WATER REACTOR SUSTAINABILITY

Idaho National Laboratory

New Monitor Streamlines High-Performance Computing

- Network contention significantly increases the time-to-solution for tightly coupled simulations on supercomputers. Researchers in the HPC group are working on algorithms to re-route messages to avoid contention, similar to avoiding traffic jams.
- This tool supports routing innovation to avoid contention and accelerate nuclear high-performance computing applications.
- The monitor consists of a 16-node ARM-based research cluster and a color display showing message size and location to indicate congestion.





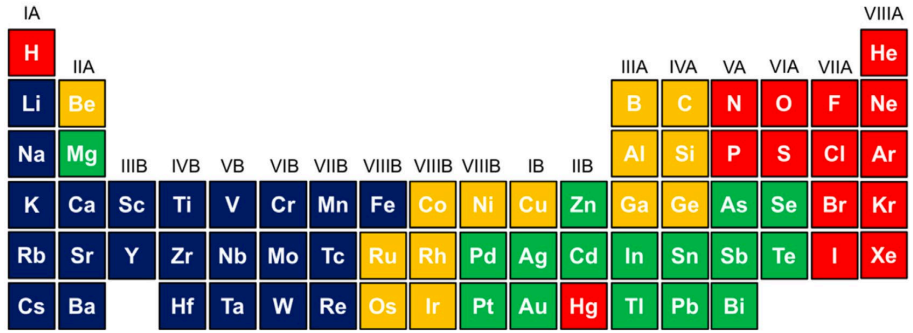
Network Contention Monitor Aims to Improve HPC Performance for Nuclear Energy Applications

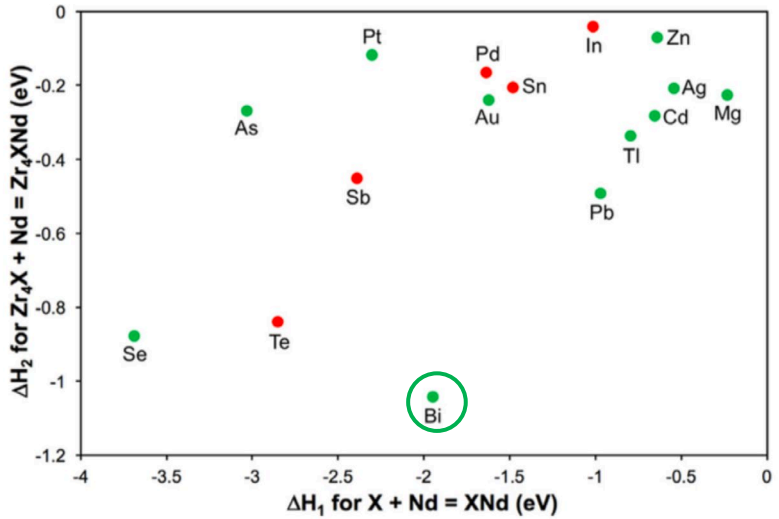
For more information:
matthew.anderson2@inl.gov

Idaho National Laboratory

New Additive Discovered to Reduce Fuel-Cladding Interaction

- The chemical reactions between fission product lanthanides and Fe-based cladding, a phenomenon called fuel-cladding chemical interaction (FCCI), poses a long-standing issue that limits the lifetime and reliability of nuclear reactors.
- One way to reduce detrimental FCCI effects is by doping metallic fuels with additives that can strongly bind with lanthanides and reduce their mobility and chemical reactivity.
- By performing computational screening of 68 elements across the periodic table, INL scientists have successfully discovered Bi as a new highly effective FCCI-mitigating additive for U-Zr fuel. Its effectiveness has been further experimentally confirmed.
- This research has been reported in a recent article in Materialia (vol. 10, 100653, 2020). https://doi.org/10.1016/j.mtla.2020.100653





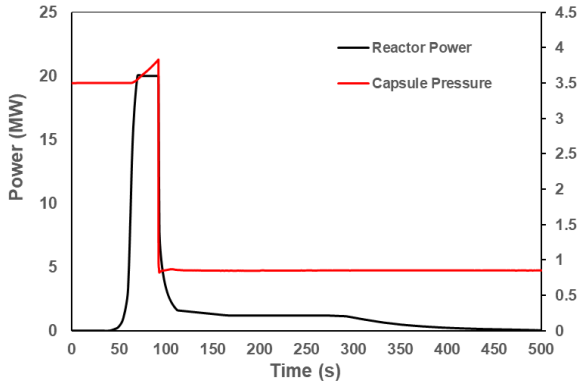
INL scientists have discovered Bi as a new FCCI-mitigating additive for U-Zr fuel

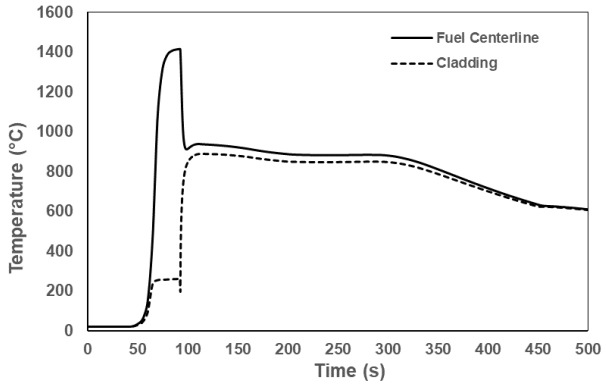
For more information:
chao.jiang@inl.gov

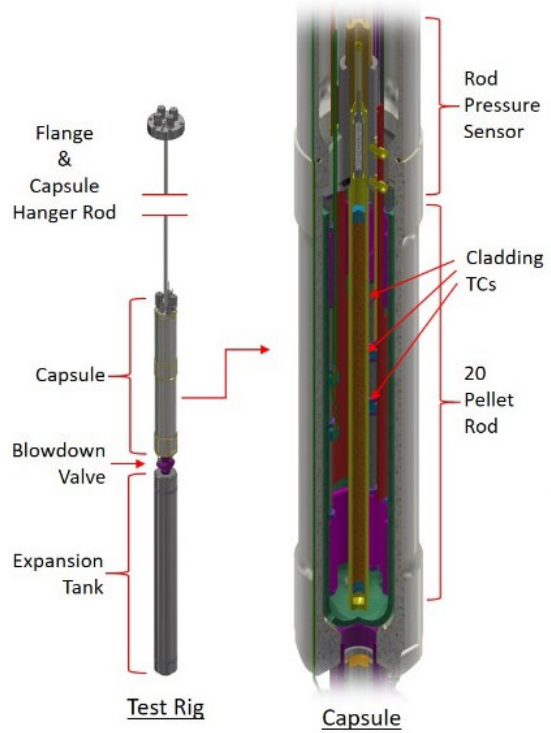
Idaho National Laboratory

Test Capsule Innovation Helps Support More Efficient Fuel Use in Reactors

- Loss-of-Coolant-Accident (LOCA) testing is a crucial R&D component to support the industry goal for increasing fuel burnup limits.
- RELAP5-3D was used to realize an innovative TREAT Facility testing capsule design, to evaluate fuel fragmentation during LOCA conditions.
  - The LOCA-SERTTA capsule CAD design rendering of structural components for the LOCA-SERTTA capsule.
  - The combination of the TREAT Facility's flexible power maneuvering and LOCA-SERTTA enable prototypic fuel and cladding temperatures during a simulated LOCA.
  - Researchers are using BISON code to further develop the test design.







LOCA-SERTTA design rendering

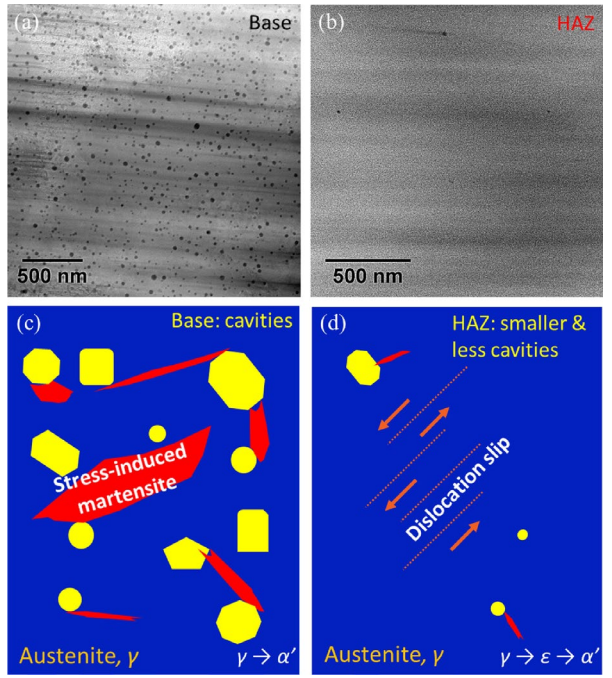
For more information
daniel.wachs@inl.gov

Idaho National Laboratory

Study Improves Understanding of Stainless Steel Reactor Materials

- After extended service, reactor components are susceptible to irradiation embrittlement and can consequentially crack prematurely and require repair for continued safe operation.
- Laser welding is a leading candidate for repair.
- This study isolates the role of cavities in the martensitic transformation in laser-welded, neutron-irradiated austenitic stainless steel. Results suggest that by controlling the cavity formation, the phase transformation of the steel can be influenced to enhance safety.
- RTE PI: K. F. Mao (Purdue U, INL) *et al*.
- Published in *Scripta Mater*, 178 (2020) 1-6 https://doi.org/10.1016/j.scriptamat.2019.10.037

First demonstration that cavity population can control the martensitic phase transformation of welded irradiated austenitic stainless steel



Comparison of irradiation-induced cavities by scanning transmission electron microscopy in (a) base metal and (b) heat-affected zone.

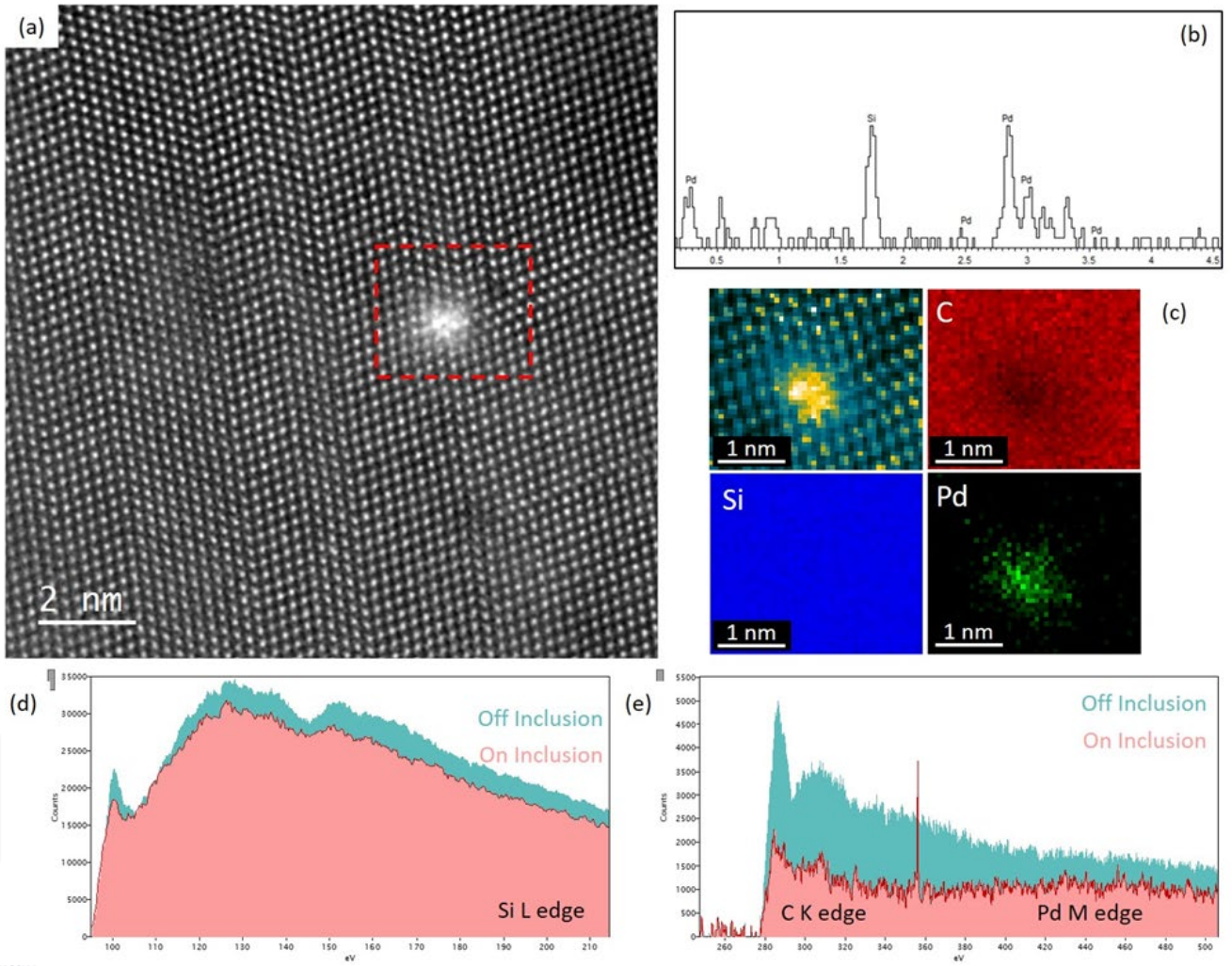
For more information:
rory.kennedy@inl.gov

NSUF Nuclear Science User Facilities

Idaho National Laboratory

Research Improves Understanding of TRISO Fuel Safety

- Researchers studied palladium (Pd) fission products in irradiated TRISO fuel to determine how it impacts faults and safety.
- In post-irradiation examination, Pd was identified as nanoscale faceted silicide precipitates. In areas with Pd, there was a decrease in carbon concentration and an increase in silicon, consistent with grain boundary observations.
- The finding provides evidence for early stage formation of a silicide.
- Work published in Journal of Nuclear Materials (J. Nucl. Mater., 532 (2020) 152043) https://doi.org/10.1016/j.jnucmat.2020.152043



Advances understanding of fission product transport in TRISO fuel to support reactor safety analyses

For more information:
isabella.vanrooyen@inl.gov

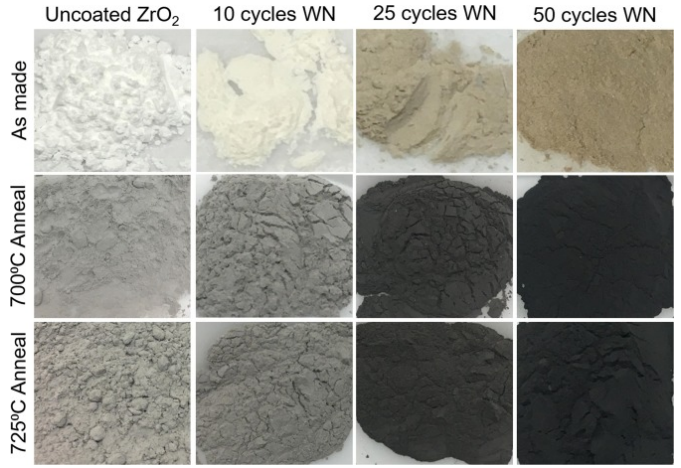
ART ADVANCED REACTOR TECHNOLOGIES

Nelson M Metropo University for tomorrow

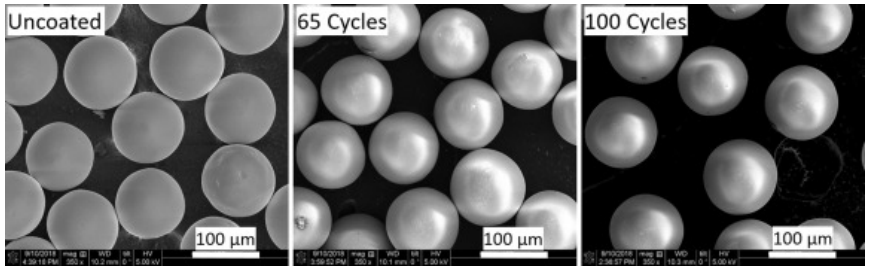
Idaho National Laboratory

First Tests of Tungsten Nitride Film as Protective Barrier to Hydrogen

- H_2 is key in a variety of energy applications, but it easily diffuses in materials, causing degradation. Environmental barrier coatings (EBCs) have been used to block H_2 diffusion and prevent embrittlement.
- Because of its high melting point, strength at high temperatures, high thermal conductivity and low H_2 retention, tungsten and tungsten nitride are currently favored EBCs.
- Nanoscale films of tungsten nitride were deposited on zirconia nanoparticles using atomic layer deposition. The atomic layer deposition (ALD) film delayed but didn't eliminate the hydrogen reaction.
- INL authors: Cynthia Adkins, Robert O'Brien
- HPC support: S. K. Bull (UC Boulder), *et al*.
- Published in *Appl. Surf. Sci.*, 507 (2020) 145019 https://doi.org/10.1016/j.apsusc.2019.145019



WN ALD coated zirconia powder after annealing in 20% H2 in N2 balance atmosphere at either 700°C and 725°C. The color change from brown to dark gray associated with the nitride decomposition can easily be seen.



SEM micrographs of uncoated, 65 cycles, and 100 cycles of WN on 100 µm diameter YSZ powder. The increase in brightness of the particles from uncoated to coated indicates deposition of the WN film.

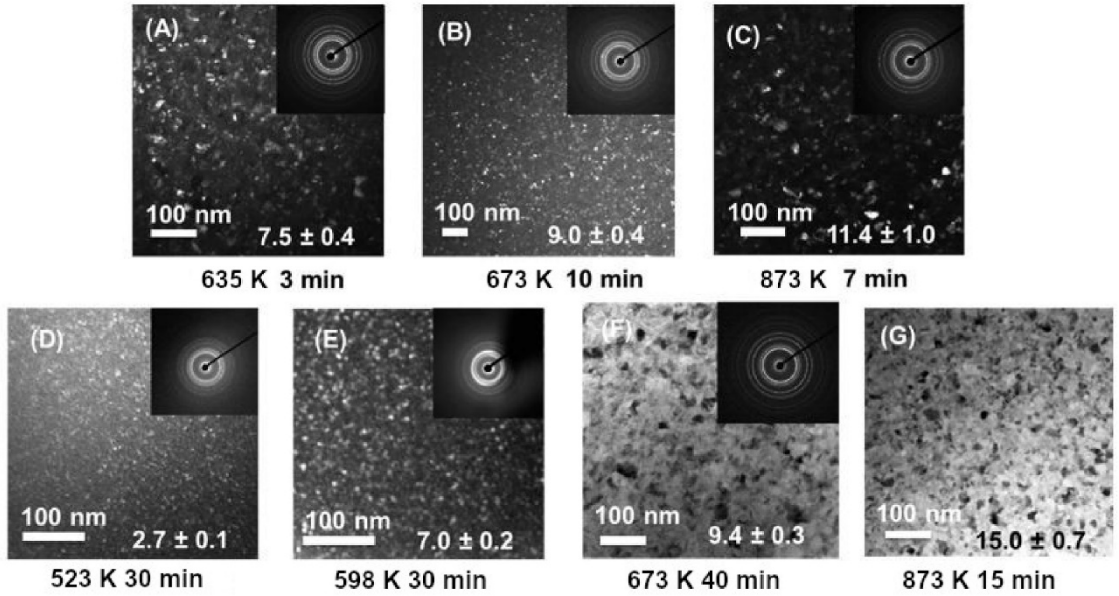
For more information:
rory.kennedy@inl.gov

NSUF Nuclear Science User Facilities

Idaho National Laboratory

New Model Developed to Improve Understanding of U_3Si_2 Fuel Behavior

- U_3Si_2 is a possible accident tolerant fuel replacement for UO_2 in light water reactors. It consists of grains that grow over time, which impacts performance.
- Researchers developed a model for normal grain growth in U_3Si_2.
- When compared to UO_2, grain growth occurs ***faster*** in U_3Si_2 at 1200 K but ***slower*** in U_3Si_2 at typical centerline temperatures.
- INL authors: Tiankai Yao, Lingfeng He
- RTE PI: T. Yao (RPI) *et al*.
- Published in *J. Nucl. Mater.*, 532 (2020) 152069 https://doi.org/10.1016/j.jnucmat.2020.152069



Grain growth experiments carried out at increasing temperatures. (A) and (D) show the conditions and bright field images used to crystalize the samples with the initial grain size. (B) and (C) show the conditions, images, and average grain sizes in the lamella that used short annealing times. (E)–(G) show the conditions, images, and average grain sizes in the lamella that used long annealing times.

New grain growth model shows grain growth in U_3Si_2 happens faster at 1200 K and slower at typical centerline temperatures when compared to UO_2

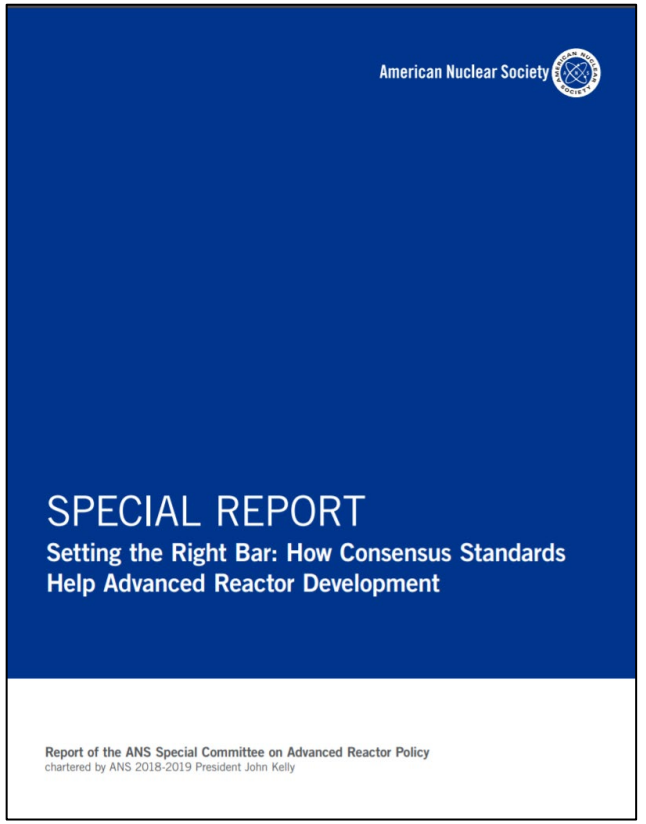
For more information:
rory.kennedy@inl.gov

NSUF Nuclear Science User Facilities

Idaho National Laboratory

ANS Highlights INL's Work on Advanced Reactor Policy

- Nuclear News featured INL researcher Piyush Sabharwall's participation on the American Nuclear Society (ANS) Special Committee on Advanced Reactor Policy. The Committee recently published a special report: *Setting the Right Bar: How Consensus Standards Help Advanced Reactor Development*.
- The feature lays out the report's recommendations, provides an overview of the work of standards-development organizations and highlights the thought leadership one INL researcher provides with other advanced-reactor experts from national laboratories, industry, utilities, and universities.
- The report also highlights the main findings of an ANS/NRC workshop held to develop a strategic vision for advanced-reactor standards, identifying key standards to be developed or updated.
- More information is available at https://www.ans.org/policy/

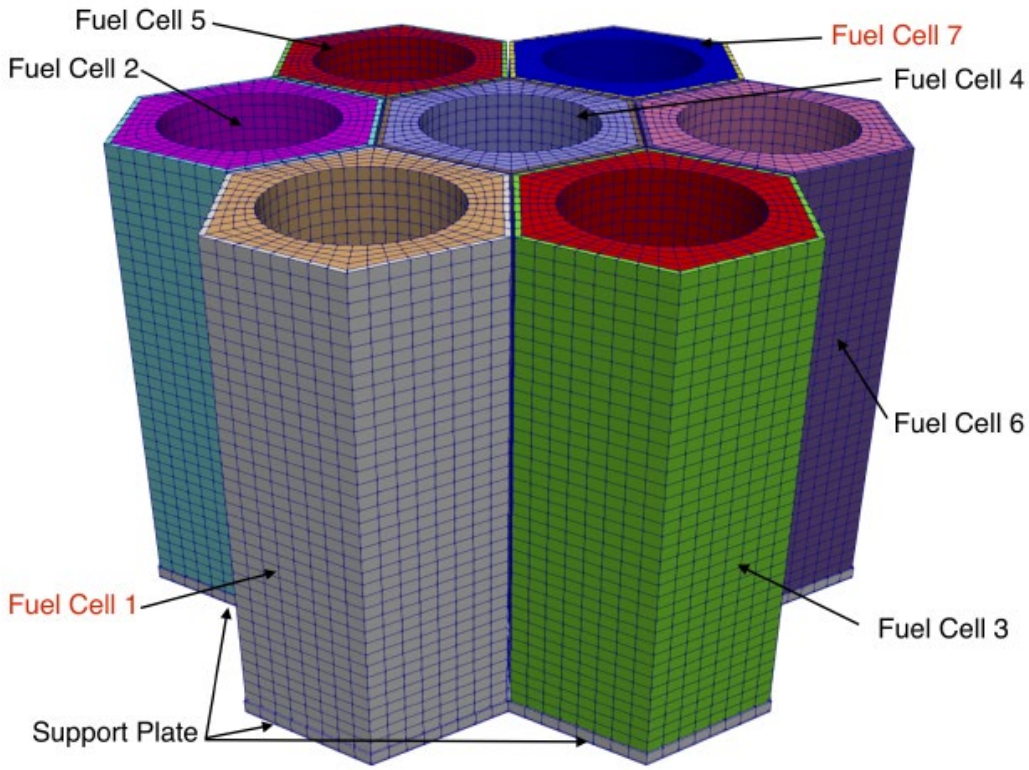


For more information:
piyush.sabharwall@inl.gov

Idaho National Laboratory

New Modeling Capabilities Pave the Way for Advanced Reactor Technology

- New modeling advances continue supporting advanced reactor technology development.
- Explicit modeling has been created of the PBMR-400 pebble transient temperature response.
  - Several multi-scale pebble coupling approaches were tested for the important PBMR-400 benchmark, with one pebble per mesh element in the active core region.
  - The results show good conservation behavior and the stability of the coupling.
- Modeling of heat pipe microreactors with hexagonal cladding has been developed.
  - A set of tests has been created to investigate an approach to modeling the thermal expansion phenomena in MOOSE without relying on a thermomechanical solution for the entire core.



For more information:
javier.ortensi@inl.gov

Idaho National Laboratory

New Web-Based Tool Simplifies High-Performance Computing Access

- A new web browser-based external HPC tool was made available to all HPC users.
- HPC OnDemand provides a fully-functional remote Linux Desktop or Jupyter Notebook with HPC file system access, login node access, and compute node access.
  - External users outside the firewall https://hpcondemand.inl.gov
  - INL employees on VPN or at work https://ondemand.hpc.inl.gov
  - Learn more about HPC OnDemand with our training videos - http://hpcweb.hpc.inl.gov/trainingvideos/how_to_use_INL_systems/ondemand_getting_started/.
- Access to INL HPC resources is available at new Nuclear Computational Resource Center website: https://inl.gov/ncrc/.

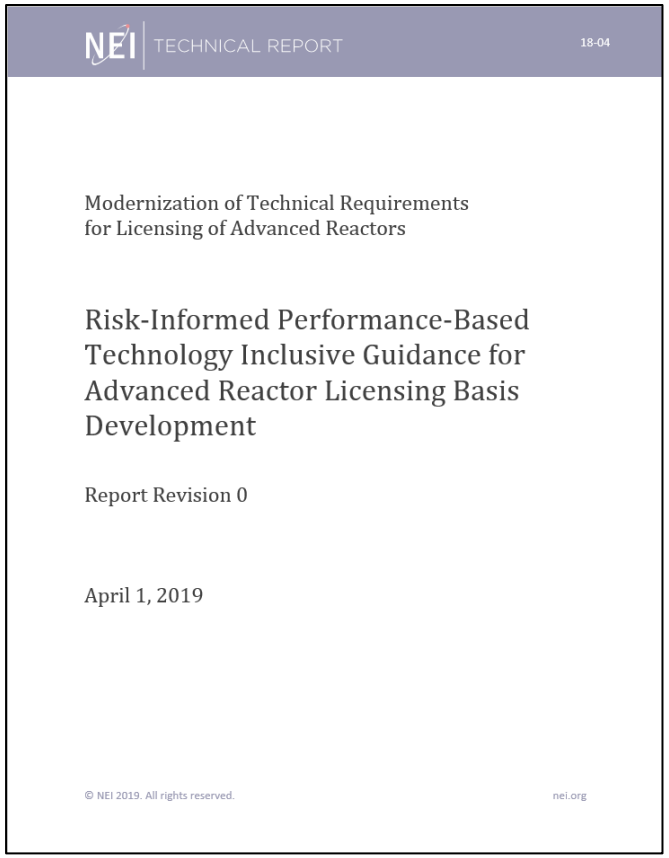
HPC OnDemand is a one-stop shop solution for HPC resources

For more information:
tami.grimmett@inl.gov

Idaho National Laboratory

Licensing Modernization Initiative Produces New Licensing Guidance for Advanced Reactors

- Directed by INL, Southern Company's Licensing Modernization Project (LMP) proposed a new basis for licensing non-light water reactors.
  - Nuclear Safety & Regulatory Research staff of Jim Kinsey, Wayne Moe, and Mark Holbrook (retired) were key researchers on this activity.
  - The approach is sanctioned by NEI's Advanced Reactor Regulatory Task Force.
  - The approach is risk-informed, performance-based, technology-inclusive licensing.
  - Nuclear Regulatory Commission staff drafted Commission SECY-19-0017 and Regulatory Guide (DG-1353) to support formal regulatory endorsement.
- On May 26, 2020, the NRC Commission **unanimously** voted to adopt LMP.


NEI TECHNICAL REPORT 18-04

Modernization of Technical Requirements for Licensing of Advanced Reactors

Risk-Informed Performance-Based Technology Inclusive Guidance for Advanced Reactor Licensing Basis Development

Report Revision 0

April 1, 2019

nei.org

This approach changes many longstanding NRC policies that constrained advanced reactor development and commercial deployment

For more information:
jim.kinsey@inl.gov

U.S. DEPARTMENT OF ENERGY | Office of Nuclear Energy

Southern Company

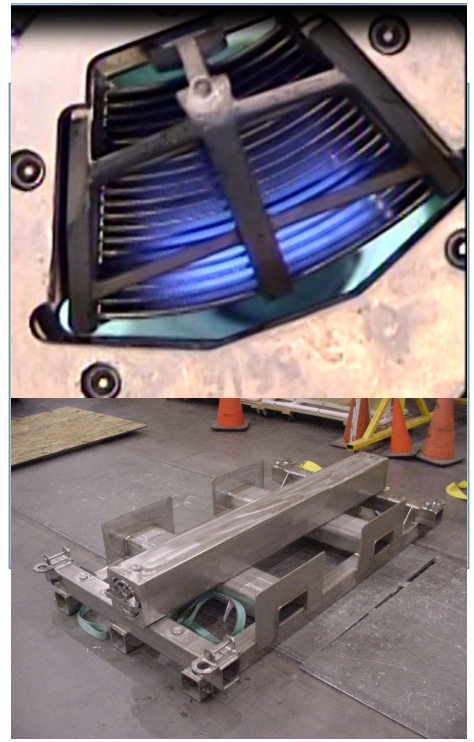
NEI

U.S.NRC

Idaho National Laboratory

ATR Fuel Management Assumes Key Engineering Roles

- NS&T ATR Fuel Management (Jeff Brower) has been designated as the Design Authority (DA) for both the ATR Low Enriched (LOWE) Fuel Elements and the ATR Fresh Fuel Shipping Containers (FFSC).
- An INL DA establishes engineering requirements and verifies that the engineering design and end product meet the functional and operational requirements. The DA retains ultimate responsibility for the technical output of the program.
- **LOWE** - The DA provides technical oversight for the development and qualification of a LOWE Uranium-Molybdenum (U-Mo) monolithic fuel, the necessary fabrication technology and infrastructure to facilitate the commercial production of this fuel, and the analysis and testing to facilitate conversion of the ATR.
- **FFSC** - The DA identifies the critical characteristics necessary to preserve the safety function and applies quality requirements for procurements based on radiological material at risk, mission importance, safety of workers, public, environment, equipment, and other differentiating criteria.



For more information:
jeffrey.brower@inl.gov

NS&T provides technical leadership to support ATR operations

Idaho National Laboratory

INL Collaborates on Six Small Business Innovation Research Awards

- INL Measurement Science engineers supported five companies that have been awarded **six SBIR projects for the development of advanced sensors and nuclear instrumentation in FY-20:**
  - Intelligent Optical System, Inc. (Torrance, CA): Advanced Laser Ultrasonic Sensor for Fuel Rod Characterization
  - Applied Nanotech, Inc. (Austin, TX): Printed Sensors for Monitoring Reactor Health
  - Analysis and Measurement Services Corp. (Knoxville, TN): VERA Software Validation using In-Plant Data
  - Analysis and Measurement Services Corp. (Knoxville, TN): Online Monitoring System to Support Autonomous Remote Microreactor Operations
  - X-wave Innovations, Inc. (Gaithersburg, MD): Ultrasonic Residual Stress Reliever System for Mitigation of Stress Corrosion Cracking in Spent Nuclear Fuel Dry-Storage Canister Welds
  - Advanced Cooling Technologies, Inc. (Lancaster, PA): High Power and High Temperature Heat Pipes for Small and Modular Reactors.

INL research contributes to the commercialization of nuclear instrumentation for existing and advanced reactors

For more information:
pattrick.calderoni@inl.gov

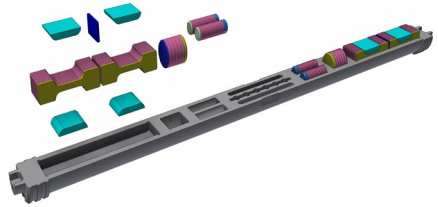
Idaho National Laboratory

NSUF Projects Complete Two Preliminary Design Reviews

Studying chromium-coated Zircaloy accident-tolerant fuel claddings

Project Collaborator: The Ohio State University

Accomplishment: Completed preliminary design review for TREAT Facility experiment studying diffusion multiples between Zr and Cr; Mo, Nb, and Ta; Zircaloy with Cr; and Cr with Mo, Nb, and Ta.



Investigating mechanical and thermal properties of high-purity SiC for applications in light water reactors and accident tolerant fuel

Project Collaborator: Idaho National Laboratory

Accomplishment: Completed preliminary design review for the irradiation of high purity SiC samples that will be studied and then added to the NSUF Nuclear Fuels and Materials Library (NFML).

For more information:
brenden.heidrich@inl.gov

NSUF Nuclear Science User Facilities

Idaho National Laboratory

Applied Visualization Laboratory Leadership Recognized by Industry

- The proposal titled "*Virtual Reality as a State-of-the-art Tool for Training of First Responders in Disaster Response,*" by Rajiv Khadka and John Koudelka, in collaboration with Mustafa Mashal, Idaho State University, has been selected for the Center for Advanced Energy Studies Collaboration Fund 2020.
- John Koudelka has been appointed as Campus Alliance for Advanced Vizualization Executive Board – Member at Large.
- Rajiv Khadka has been appointed as Review Editor at Frontiers in Virtual Reality Journal and Review Committee for IEEE Visualization 2020.

Rajiv Khadka giving a demonstration of VR capabilities

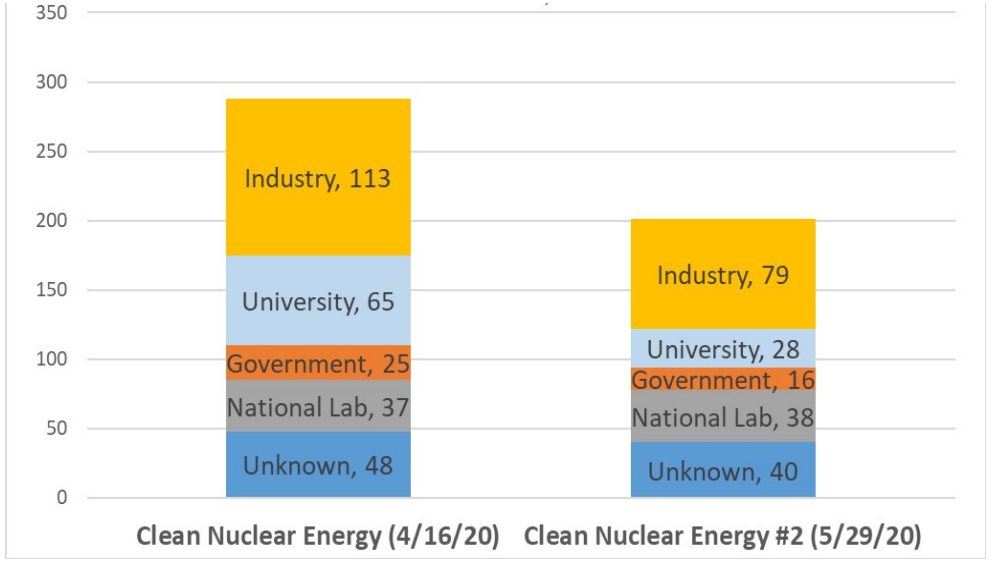
For more information:
john.koudelka@inl.gov

Idaho National Laboratory

GAIN Webinar Series: Clean Nuclear Energy for Industry

- The GAIN **Clean Nuclear Energy for Industry** Webinar Series highlights innovations in nuclear energy and integrated-energy options that may be beneficial to industrial energy applications.
- The intent is to communicate the benefits of clean, reliable, and resilient nuclear energy to the energy end-use community.
- On May 29, 2020, the second webinar in this series featured presentations by the GAIN Technology Working Group (TWG) Chairs, focusing on the unique capabilities of advanced reactor technology concepts. The workshop highlighted key operational features, options to support industrial users, and potential deployment timelines.
- The first two clean energy webinars had 489 registrants.

Webinar registrants by affiliation type



GAIN
Gateway for Accelerated Innovation in Nuclear

For more information:
lori.braase@inl.gov

Idaho National Laboratory

Shannon Bragg-Sitton Selected for Nuclear Propulsion Committee

- Dr. Shannon Bragg-Sitton (C100) has been selected for an ad hoc committee on Space Nuclear Propulsion.
- The committee was convened by the National Academies of Sciences, Engineering, and Medicine.
- This committee is charged with identifying primary technical and programmatic challenges, merits, and risks for developing and demonstrating space nuclear propulsion technologies of interest to future exploration missions. The committee review will include both Nuclear Electric Propulsion (NEP) and Nuclear Thermal Propulsion (NTP) and will nominally run through August 2020.

For more information:
shannon.bragg-sitton@inl.gov

Idaho National Laboratory

Dr. Javier Ortensi Named NEAMS Deputy for Reactor Physics

- Dr. Ortensi has worked in the development of computers codes for neutronics, heat transfer, and thermal fluids.
- He has been involved in the multiphysics modeling and simulation of reactor designs including: pressurized water, micro, prismatic and pebble bed high temperature, fast, and Training, Research, Isotopes, General Atomics (TRIGA) reactors.
- Dr. Ortensi has worked on the deployment of the U.S. Nuclear Regulatory Committee's Comprehensive Reactor Analysis Bundle (CRAB) since 2018. He currently leads the benchmark on coupled neutronics and thermal-fluids analysis of the modular high-temperature gas-cooled reactor (MHTGR-350) for the Nuclear Energy Agency's Organisation for Economic Co-operation and Development (OECD).
- He has 5 years of industrial experience with Entergy Operations, Inc. in pressurized and boiling water reactor probabilistic risk assessment, and in pressurized water reactor physics.

Dr. Javier Ortensi

For more information:
javier.ortensi@inl.gov

Idaho National Laboratory

INL Fusion Researchers Fill National Leadership Roles

- After a stint on the program committee of the American Physical Society Division of Plasma Physics Community Planning Process (APS-DPP CPP), Paul Humrickhouse was selected to serve on the Fusion Energy Sciences Advisory Committee (FESAC) subcommittee on long-range strategic planning. The committee will advise the DOE-SC Fusion Energy Sciences program on a roadmap to fusion energy based on the CPP recommendations and under a variety of budget scenarios.

- Masa Shimada was selected to serve as the topical group lead for Fusion Engineering Science in the U.S. Burning Plasma Organization. His term will run from May 2020 to April 2022.

For more information:
paul.humrickhouse@inl.gov

Idaho National Laboratory

Publications Summary

- S. Kim, R. Johns, J. Yoo, E. Baglietto, “Progress Toward Simulating Departure from Nucleate Boiling at High-Pressure Applications with Selected Wall Boiling Closures,” Nuclear Science and Engineering, 04 May 2020. https://doi.org/10.1080/00295639.2020.1743579
- A Cheniour, M. Tonks, B. Gong, T. Yao, L. He, J. Harp, B. Beeler, Y. Zhang, J. Lian. “Development of a Grain Growth Model for U_3Si_2 Using Experimental Data, Phase Field Simulation and Molecular Dynamics.” Journal of Nuclear Materials, Vol. 532. https://doi.org/10.1016/j.jnucmat.2020.152069
- K. Mao, C. Sun. C. Shiau, K. Yano, P. Freyer, A. El-Azab, F. Garner, A. French, L. Shao, J. Wharry. Role of Cavities on Deformation-Induced Martensitic Transformation Pathways in a Laser-Welded, Neutron Irradiated Austenitic Stainless Steel. Scripta Materialia, Vol. 178. https://doi.org/10.1016/j.scriptamat.2019.10.037
- S. Bull, W. McNeary, C. Adkins, T. Champ, C. Hill, R. O’Brien, C. Musgrave, A. Weimer. Atomic Layer Deposition of Tungsten Nitride Films as Protective Barriers to Hydrogen. Applied Surface Science, Vol. 507. https://doi.org/10.1016/j.apsusc.2019.145019
- E. Oliver, J. Neethling, I. van Rooyen. Investigation of the Structure and Chemical Nature of Pd Fission Product Agglomerations in Irradiated TRISO Particle SiC. Journal of Nuclear Materials, Vol. 532. https://doi.org/10.1016/j.jnucmat.2020.152043