

# NS&T Highlights April 2020

Joel Newman Hiller

June 2020



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

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**June 2020**

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# Nuclear Science & Technology

*April 2020 Highlights*



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## ***New INL-Developed Material Approved for Use in Advanced Reactors***

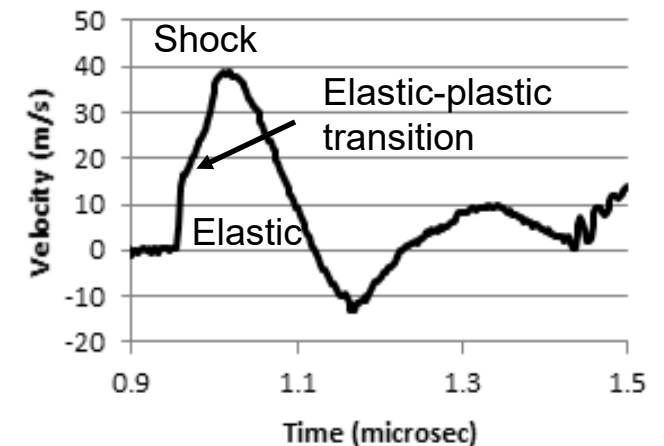
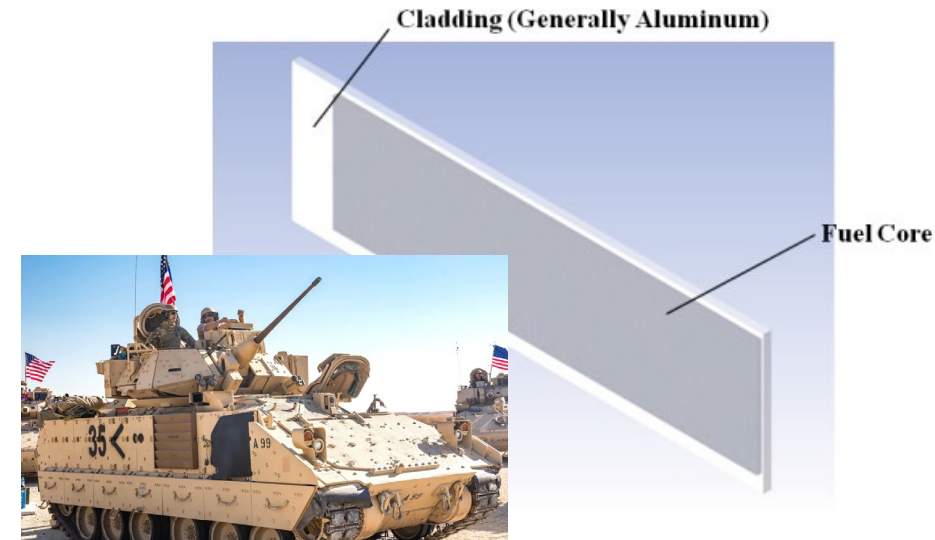
- Alloy 617 (a combination of nickel, chromium, cobalt and molybdenum) was approved for commercial use by ASME and is now formally published in the ASME Boiler and Pressure Vessel Code.
- This is the first new material added to ASME's Boiler and Pressure Vessel Code in 30 years.
- INL led the \$15 Million project over a 12-year period, in collaboration with ANL & ORNL teams.
- Alloy 617 can now be used by advanced reactor designers for high-temperature reactor applications up to 950°C, compared to earlier alloys that were limited to 750°C. It is qualified for use in HTGR, MSR and SFR designs.
- The qualification program included collection of long-term creep data and stress measurements at various elevated stress and temperature regimes.



**Alloy 617 added as the first new ASME Code material in 30 years!**

# Newly Patented Measurement Technique Enhances Materials Testing for Advanced Reactors

- James Smith and Jeff Lacy were awarded a patent for a noncontact, fiber-optic-based velocity measurement technique, designed for harsh environments.
- The stress threshold within a shock wave at which a material transitions from a purely elastic state to an elastic-plastic state is a noteworthy material property.
- Elastic-plastic transition is a function of a material's yield strength, which is an important processing/manufacturing parameter.
- US Patent #10,620,100 "Non-Contact Velocity Measurement Instruments and Systems, and Related Methods."
- Full patent may be viewed at <https://patentimages.storage.googleapis.com/df/a9/e8/81a4e6733f97a5/US10620100.pdf>.

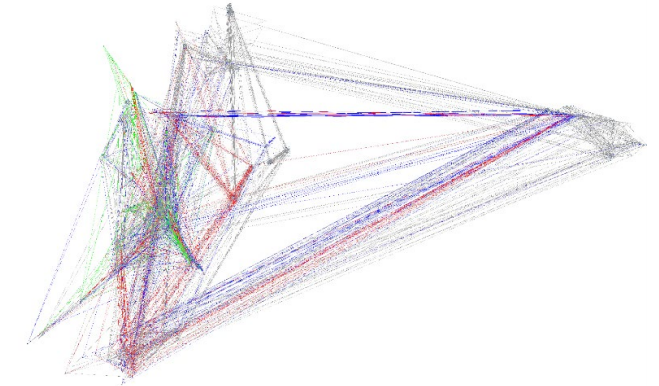


**Technique has broad application across nuclear fuels, armor, advanced manufacturing and integrated materials systems.**



# INL's Sawtooth Supercomputer Advances INL's Ability to Keep Computing Resources Safe from Malware

- A new capability was developed to identify and reverse engineer novel malware using deep learning.
- A new scientific language model was trained on scientific publications from arXiv.org, providing:
  - Enhanced accuracy for Natural Language Processing (NLP) tasks involving scientific text
  - The opportunity for creating other, domain-specific language models.
- This work was presented at the lab-wide *Big Data, Machine Learning and Artificial Intelligence* symposium Friday, April 17<sup>th</sup> with over 200 participants.

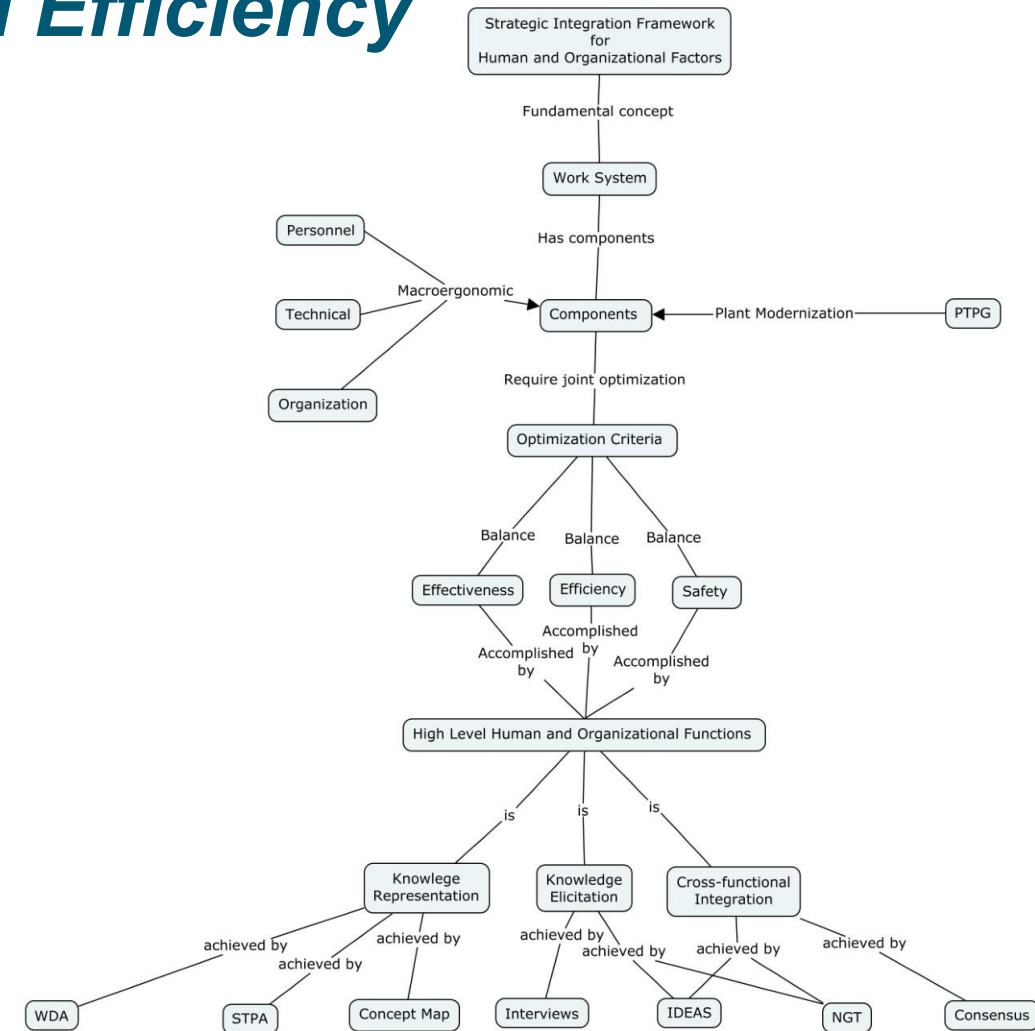


Control flow graphs showing regions of **binary clones** between the GonnaCry ransomware and an obfuscated ransomware for easy and rapid identification of the obfuscated malware.

INL Demonstrates New NLP Capabilities for High Performance Computing.

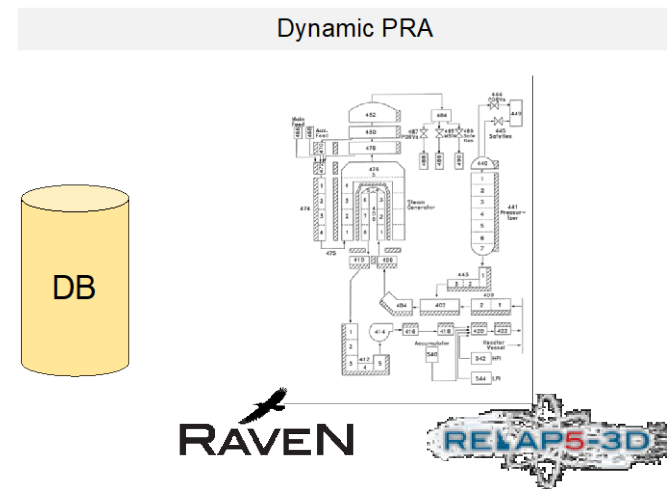
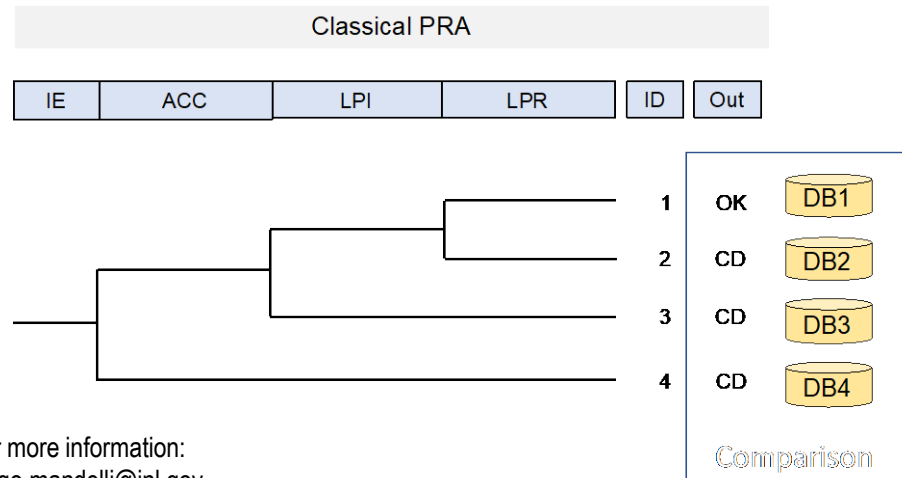
# New Framework Helps Nuclear Plants Modernize, Improving Safety and Efficiency

- Human factors researchers developed a framework for effectively integrating of organizational and human factors when modernizing plants.
- The new framework specifies four aspects to consider to jointly optimize personnel, technical, and organizational elements:
  1. Knowledge elicitation
  2. Knowledge representation
  3. Cross-functional integration
  4. Systems engineering.
- Report supports Light Water Reactor Sustainability Plant Modernization Pathway and allow utilities to optimize the effectiveness, efficiency and safety of their plant systems.



# INL Risk Assessment Methods Help Improve Power Plant Safety

- Researchers were asked to bring together different approaches to Probabilistic Risk Assessment:
  - Classical PRA: based on Boolean structures (e.g., event trees and fault trees)
  - Dynamic PRA: based on simulation (e.g., RELAP5) and stochastic sampling tools (e.g., RAVEN).
- The team developed methods within RAVEN to identify inconsistencies between classical and dynamic PRA, and integrate data generated by dynamic PRA into existing classical PRA. They also created time-dependent classical PRA models such as event trees, fault trees and reliability block diagrams.
- This research will improve the fidelity of existing classical PRA when dealing with complex dynamic conditions, both external events (e.g., seismic scenarios) and human-related events (e.g., FLEX operations).



*Graphical visualization of one of the methods employed to compare a database of simulated transients and the sequences of an event tree*

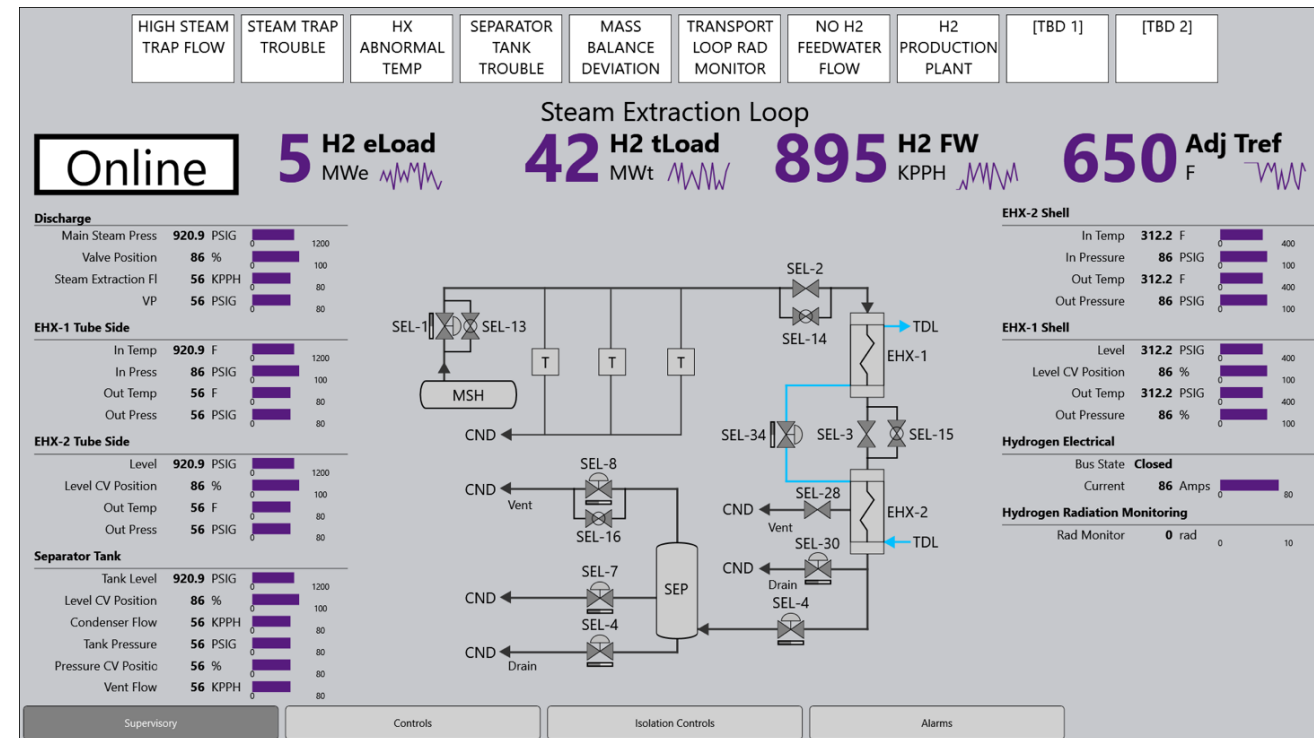
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# New Interface Supporting Hydrogen Production Can Help Nuclear Plants Operate More Efficiently

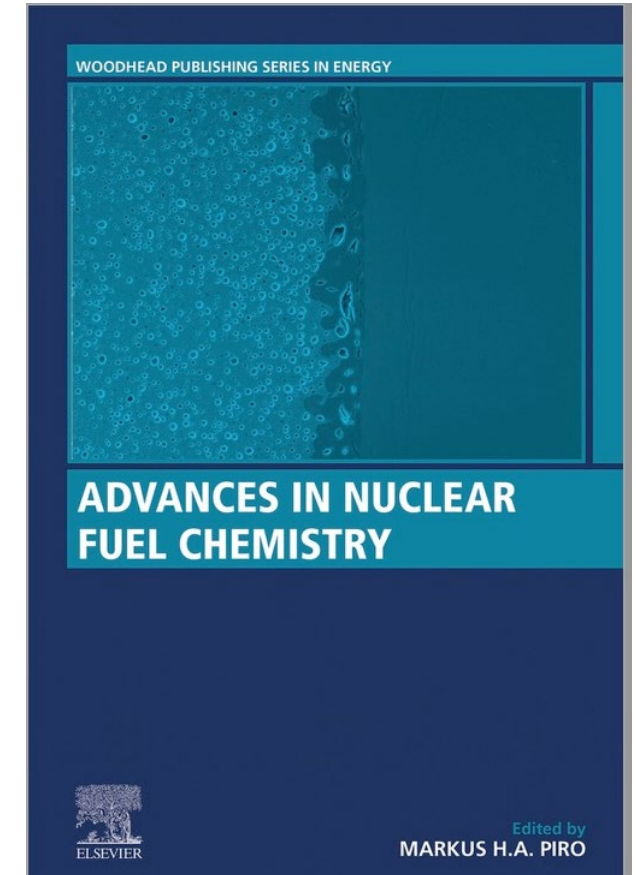
- Human factors researchers developed an **interface** to support steam extraction from a nuclear plant model to support **joint electricity-hydrogen flexible nuclear operations**.
- A fully functional prototype was developed using the full-scope Generic Pressurized-Water Reactor simulator in the Human Systems Simulation Laboratory.
  - Includes new steam extraction model
  - Includes new digital control screens and procedures for controlling process
  - The human factors process to develop and evaluate the new operation is documented in INL/EXT-20-57880.



The prototype interface supports the development of joint electricity-hydrogen nuclear operations

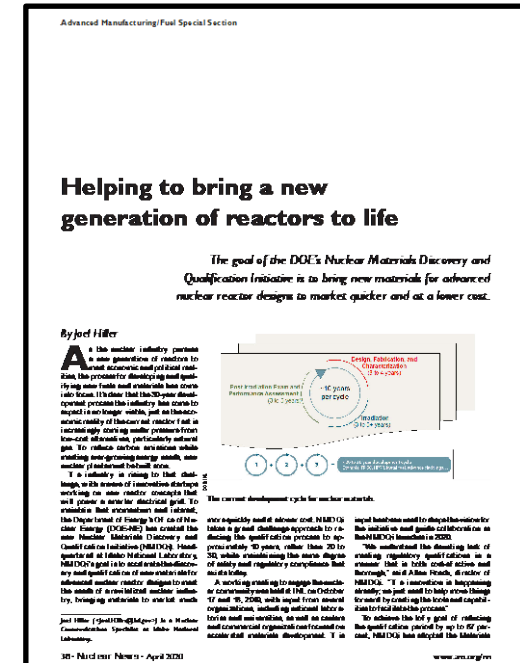
# INL Researchers Contribute to Comprehensive Book Published on Nuclear Fuel Chemistry

- Researchers made contributions to the following chapters in a new, comprehensive book on advances in nuclear fuel chemistry:
  - **Research Reactor Fuels**
    - Contributing INL authors: Mitchell K. Meyer, Dennis D. Keiser, Jr., Jan-Fong Jue and Eric Shaber
  - **Advances in Fuel Fabrication and Other Power Reactor Fuels**
    - Participating INL author: Paul Demkowicz
- “*Advances in Nuclear Fuel Chemistry* presents a high-level description of nuclear fuel chemistry based on the most recent research and advances. Contributors from all around the world cover all aspects of both the conventional uranium-based nuclear fuel cycle and non-conventional fuel cycles, including mining, refining, fabrication, and long-term storage, as well as discussing emerging nuclear technologies, such as accident tolerant fuels and molten salt materials.”
- Markus H. A. Piro (ed.) *Advances in Nuclear Fuel Chemistry*  
United Kingdom: Elsevier, (2020) ISBN: 978-0-08-102571-0



# INL Contributions to Advanced Materials Research Featured in Nuclear News Magazine

- A full-length feature on the Nuclear Materials Discovery and Qualification Initiative (NMDQi) is in the April Nuclear News magazine including quotes and content from Allen Roach, Isabella van Rooyen and Steve Hayes.
- NMDQi is an NSUF-funded initiative with the goal to “take a Grand Challenge approach to accelerate development and qualification of new nuclear materials and fuels for future advanced reactor technologies.”
- A vision for NMDQi was issued in March as INL/EXT-20-57732.



National exposure as a result of this feature will help attract collaborators and partners to meet the initiative goals.

For more information:  
robert.roach@inl.gov



**NMDQi** Nuclear Materials Discovery and Qualification Initiative



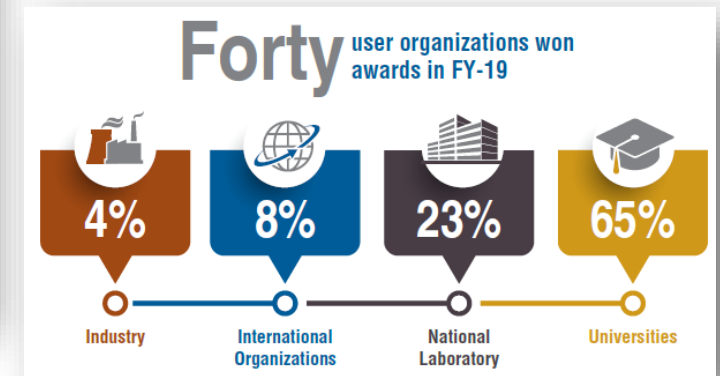
# Nuclear Science User Facilities Completes Two Major Reports Furthering Advanced Nuclear Research

## FY 2019 Annual Report

- Technical reports on NSUF projects
- Q&A with Mike Worley, Associate Deputy Assistant Secretary for Reactor Fleet and Advanced Reactor Deployment
- NSUF highlights and GAIN collaborations
- Nuclear Fuels and Materials Library update
- Year in the Life of NSUF

## Nuclear Materials Discovery and Qualification Initiative (NMDQi) Vision Report

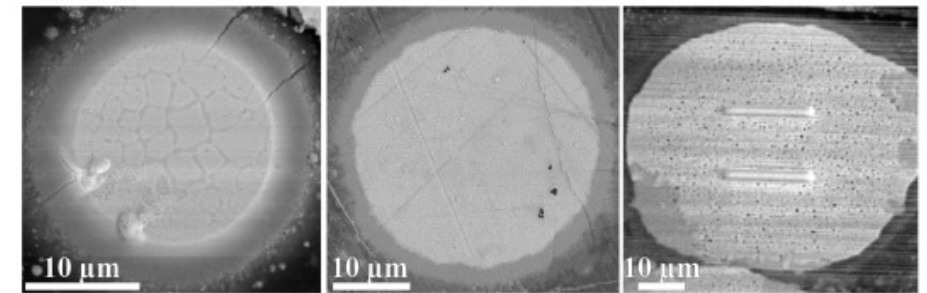
- Summarizes tools and capabilities needed for the discovery, optimization and utilization of new nuclear materials to realize the next stage in the development and deployment of nuclear energy systems.





# ***Novel Approach to Determining Burnup Supports More Efficient Fuel Usage in Reactors***

- A detailed and precise knowledge of the burnup of fissile isotopes and the composition of fuel is important for efficient reactor operation and for the effective utilization of nuclear fuels.
- INL researchers, supported by the NSUF Instrument Scientist program, developed Atom Probe Tomography (APT) as a novel method for determining local burnup in irradiated fuels with a minimal amount of waste production.
- The approach was demonstrated using as-received low-enriched U-7Mo fuel for enrichment uniformity and on the irradiated fuels at two different burnup levels.
- The method provides U enrichment and local burnup with an unprecedented high spatial resolution based on the quantification of isotopic ratios of U.



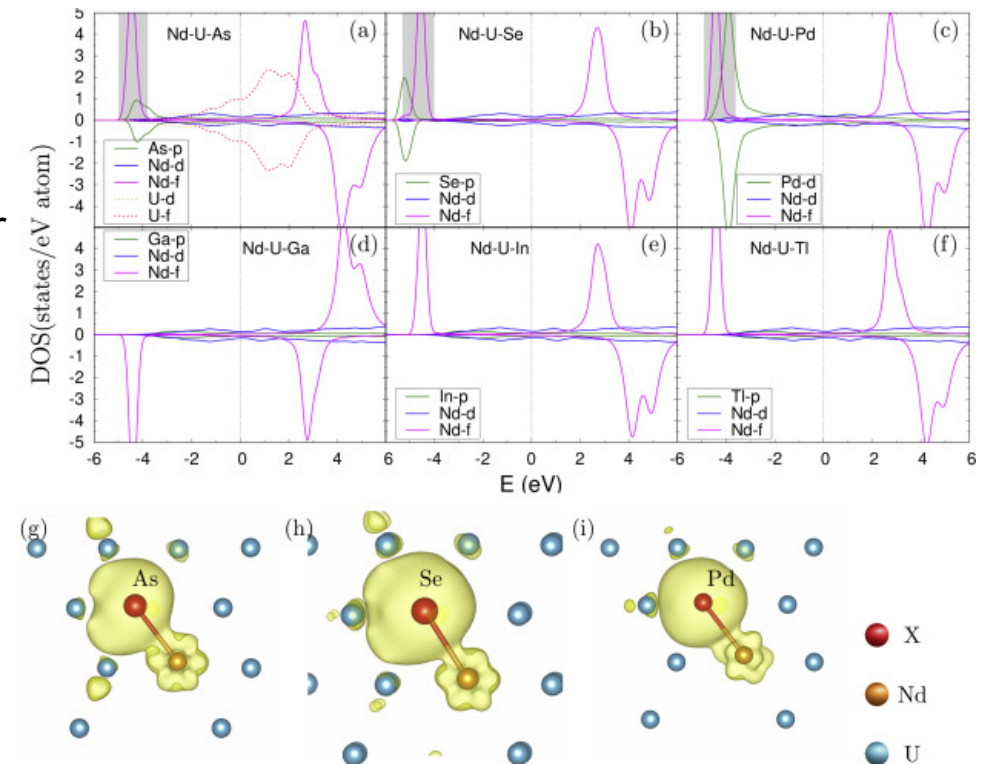
*SEM images of unirradiated (left), intermediate burnup (middle) and high burnup sample (right) of U-7Mo coated with ZrN and embedded in Al matrix.*

Published in: *J. Nucl. Mater.*, 528 (2020) 151853  
<https://doi.org/10.1016/j.jnucmat.2019.151853>

**A new method using APT determines local burnup  
in irradiated fuels with minimal waste.**

# New Principles Developed to Reduce Degradation of Nuclear Fuel

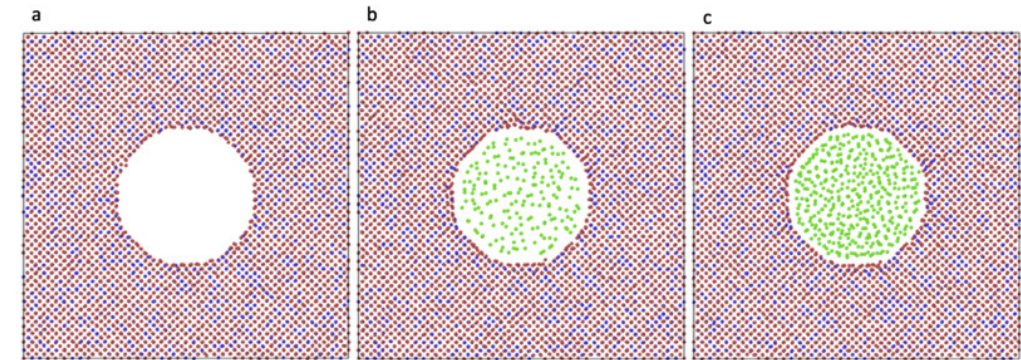
- Lanthanide fission products in uranium metallic fuels chemically react with cladding materials, leading to degradation of the cladding.
- Current approaches to this challenge involve a trial and error search for dopants that limit the mobility of the lanthanides.
- Utilizing HPC resources supported by the NSUF, INL researchers with collaborators at the University of Idaho and LANL have developed principles to identify dopants that can hold lanthanide fission products within uranium-based metallic fuels.
- The new methodology correctly identifies known dopants and has been used to predict novel dopants, including Arsenic and Selenium, for use in future uranium-based metallic fuels.



Published in: *J. Nucl. Mater.*, 529 (2020) 151922  
<https://doi.org/10.1016/j.jnucmat.2019.151922>

# Equation Improves Understanding of Uranium-Molybdenum Fuel Performance

- U–Mo fuel undergoes significant swelling during reactor operation, and accurate prediction of fuel evolution under irradiation is important.
- Knowledge of the correct thermodynamic properties is central to fuel performance modeling codes.
- INL researchers utilized HPC resources provided by the NSUF to study Xenon bubbles in the fuel, describing the energetic relationship of Xe bubbles with voids and Xe substitutional atoms.
- Results of the calculations were used to develop an equation of state for bubble pressure as a function of molar volume and temperature.



A Xe bubble at 500 K with a diameter of 7.1 nm in U–10Mo as a function of time, starting from a void (a), to a Xe/vacancy ratio of 0.16 (b), and a Xe/vacancy ratio of 0.32 (c). Red atoms are U, blue atoms are Mo and green atoms are Xe

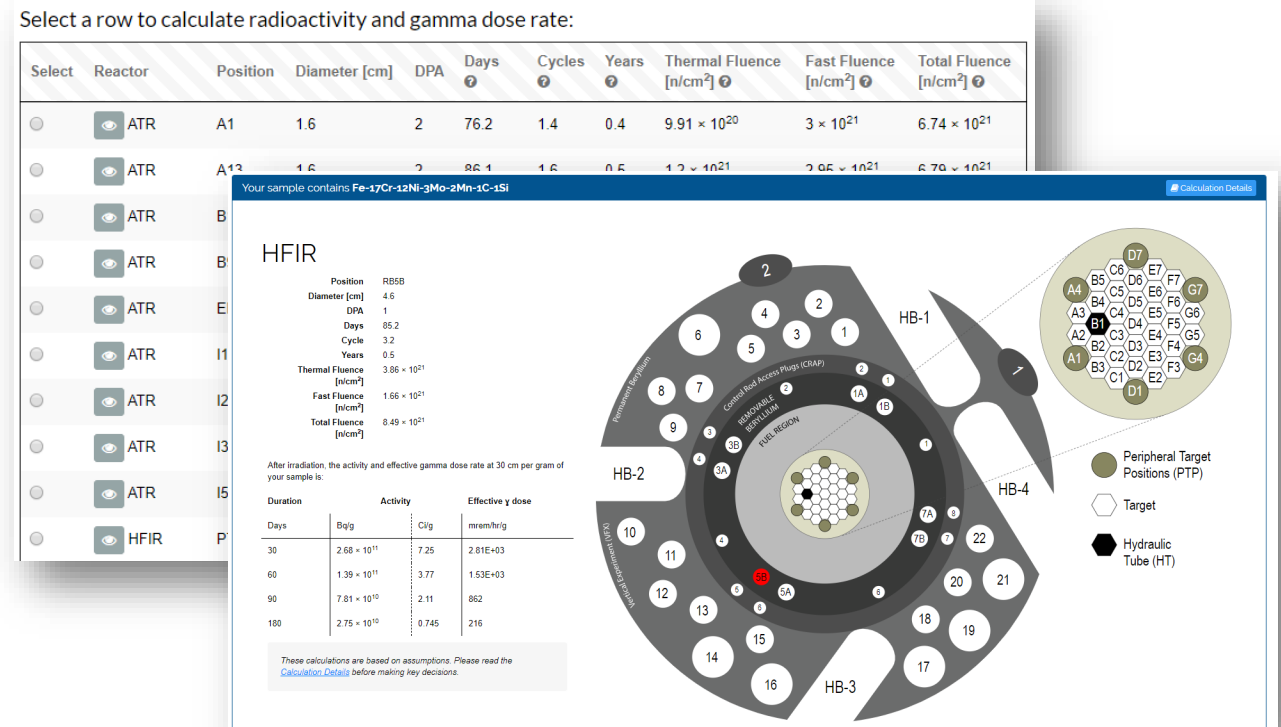
Published in: *J. Nucl. Mater.*, 530 (2020) 151961  
<https://doi.org/10.1016/j.jnucmat.2019.151961>

**A new equation of state developed for Xenon bubbles helps better predict U-Mo fuel evolution under irradiation.**



# New Tool Released to Calculate Radiation Damage and Streamline Experimental Research

- The Reactor Activation and Damage (RAD) Calculator gives researchers the ability to calculate radiation damage quickly and accurately.
- Users specify an irradiation time (in days) or damage goal (dpa) and enter material formulation.
- With this information, the tool gives possible NSUF reactors that can accomplish their goals.
- Users can also see estimates for how hot the material will be after the experiment, guiding how, when and where post-irradiation examination can be done.
- It is available at the NSUF website: <https://nsuf-infrastructure.inl.gov/Calculator>





# ***New Gamma Irradiator Strengthens Research and Funding Opportunities***

- This new high dose rate gamma irradiator, installed in the Energy Innovation Laboratory, strengthens INL's Radiation Chemistry Program by providing the ability to probe the effects of the interaction between gamma radiation and materials.
- The Foss Therapy Services Model 812  $^{60}\text{Co}$  gamma irradiator is vital for cutting-edge radiation chemistry and physics research.
- The high gamma dose rate, greater than 20 kilograys per hour, generates significant potential for future sources of funding.
- The irradiation chamber accommodates a wide variety of samples.



# *HPC Server Improves High-Performance Computing Access to Accelerate Nuclear Energy Innovation*

- The MOOSE and High-Performance Computing teams finished standing up a new enterprise Gitlab server for external collaborative development with full auditing and logging capabilities.
  - The server supports multifactor and single-sign-on authentication mechanisms and can be accessed externally without VPN or SSH forwarding.
  - This capability is critical for ANL and INL collaboration on Griffin, the new NEAMS transport and depletion application.
- A new code access mechanism has been rolled out allowing external collaborators to access pre-built executables of many MOOSE-based codes.
  - Applications are compiled for use on the high-performance clusters: Sawtooth, Falcon, and Lemhi.
  - Applications can be used for analysis without requiring each user to compile codes first.



**The new repository manager improves collaboration, licensing and distribution of nuclear modeling and simulation codes.**

# *New TREAT Sodium Loop Cartridge Aids Safety Research*

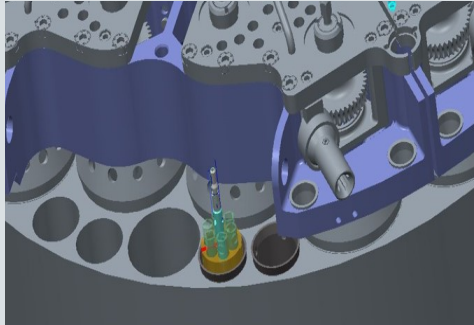
- The test loop is complete and awaiting shakedown/other testing at TerraPower's laboratory in Everett, WA.
- The TREAT sodium loop cartridge supports the configurations necessary to conduct liquid metal-cooled fuel safety research experiments with up to seven uranium- or plutonium-bearing fresh or preirradiated fuel pins.
- It is a reusable test platform that will provide experimenters a prototypic environment that recreates the thermal and hydraulic conditions of a typical Sodium-Cooled Fast Reactor (SFR).
- The sodium loop cartridge is a critical experiment vessel in establishing the capability for TREAT to perform SFR fuel safety research.
- Collaboration involves design, fabrication and testing at both INL and TerraPower facilities.



**The test loop aids fuel safety research  
for advanced reactors**



# Nuclear Science User Facilities Collaborations Pave the Way for Advanced Reactor Materials Development



## **Advanced Materials for Reduced Small Modular Reactor (SMR) Costs**

*Project Collaborator:* NuScale

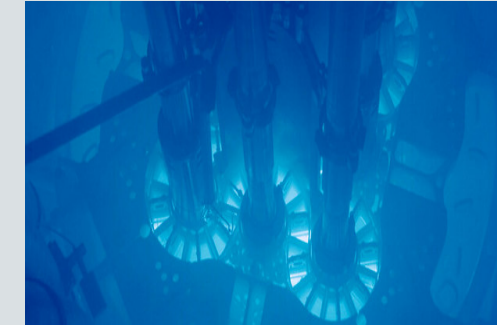
*Accomplishment:* Completed preliminary design review for irradiation testing of alternative materials for SMR lower containment vessel.



## **Qualifying Advanced Manufacturing Methods**

*Project Collaborator:* Boise State University

*Accomplishment:* Completed tensile testing for neutron irradiation effects on powder metallurgy-hot isostatic pressed (PM-HIP) steels and Inconel alloys



## **Qualifying Innovative Joining and Welding Techniques**

*Project Collaborator:* Purdue University

*Accomplishment:* Completed preliminary design review for irradiation performance of electron-beam welds of A508, class 1, grade 3 pressure vessel steel



# ***INL Plays Major Role in Organizing Clean Energy Workshops***

## **Clean Energy for Industry**

- Held April 16, cosponsored by GAIN, NEI and EPRI
- Featured four U.S. utilities that are exploring new applications for nuclear energy, with a focus on hydrogen generation.
- Moderated by Dr. Shannon Bragg-Sitton, NS&T Lead for Integrated Energy Systems
- 210 participants from national laboratories, DOE, academia, industry and government.
- Materials and recording at <https://gain.inl.gov/SitePages/GAINWebinarSeries.aspx>

## **Tri-Laboratory Consortium**

- The workshop report was recently released for the 2019 Tri-Laboratory Consortium, co-organized by INL, the National Energy Technology Laboratory and National Renewable Energy Laboratory
- The workshop goal was working toward a common suite of tools to support the design, analysis and optimization of advanced, integrated energy systems.
- Workshop report is available at <https://www.netl.doe.gov/energy-analysis/details?id=4449>

## **Solve Climate by 2030**

- Webinar hosted April 7 by CAES
- Speakers focused on market-based solutions for climate change, including nuclear.
- The nuclear discussion focused on meeting energy demands in the industrial and transportation sectors, in addition to electricity, to introduce vast amounts of clean energy in our communities.
- The role of microreactors, small modular reactors, and large-scale current/advanced reactors were discussed.
- <http://www.solveclimateby2030.org/>

# ***GAIN Co-Sponsors Webinar to Discuss HALEU Fuel Supply Chain and Speed Advanced Reactor Development***

- GAIN, NEI, and EPRI cosponsored the High-Assay Low Enriched Uranium (HALEU) Webinar on April 28-29, 2020. This was GAIN's first major two-day workshop in webinar format, with approximately 250 attendees from the nuclear industry, government, and national laboratories. In addition, over 180 questions were submitted for the speakers during Q&A. The presentations and dialogue will help to inform the appropriate path forward by the stakeholder community to support a future robust HALEU supply chain.
- The objective was to inform stakeholders on the status and challenges associated with HALEU for fuel fabrication and reactor development. The webinar covered various aspects of HALEU supply (demand, enrichment, conversion, deconversion, transportation, etc.) with a focus on the 10-20% enrichment range.
- Presentations available at <https://gain.inl.gov/SitePages/GAINWebinarSeries.aspx>



**HALEU Webinar**  
April 28-29, 2020

**Objectives:** The High-Assay Low-Enriched Uranium (HALEU) Webinar will inform stakeholders on the status and challenges associated with HALEU for fuel fabrication and reactor development. The webinar will cover the following aspects of HALEU supply with a focus on the 10-20% enrichment range:

- Anticipated demand and timeline projections for HALEU
- Enrichment, conversion, and deconversion
- Transportation needs
- Legislative and regulatory issues

**GAIN** Gateway for Accelerated Innovation in Nuclear | **EPRI** | **ELECTRIC POWER RESEARCH INSTITUTE** | **NEI** NUCLEAR ENERGY INSTITUTE

# ***ANS Young Members Group Holds Webinar Focused on INL's Achievements and Current Work***

- On April 15, the American Nuclear Society Young Members Group held a webinar about INL. 1,097 participants from a total of 39 countries attended.
- Panelists included INL Director Mark Peters and Director of the National Reactor Innovation Center Ashley Finan.
- The group discussed INL's history and achievements, along with current initiatives and what's in store for the lab.
- In addition to 71 INL registrants, there was good representation from other national and international laboratories, federal agencies (including DOE, NRC, GAO, NASA), utilities / utility groups (including INPO, EPRI, NEI, Utilities Service Alliance, Dominion, Exelon, TVA, Xcel), universities (168 registrants) and industry (including Westinghouse, Bechtel, BWXT, Framatome Inc, SCK CEN).

For more information:  
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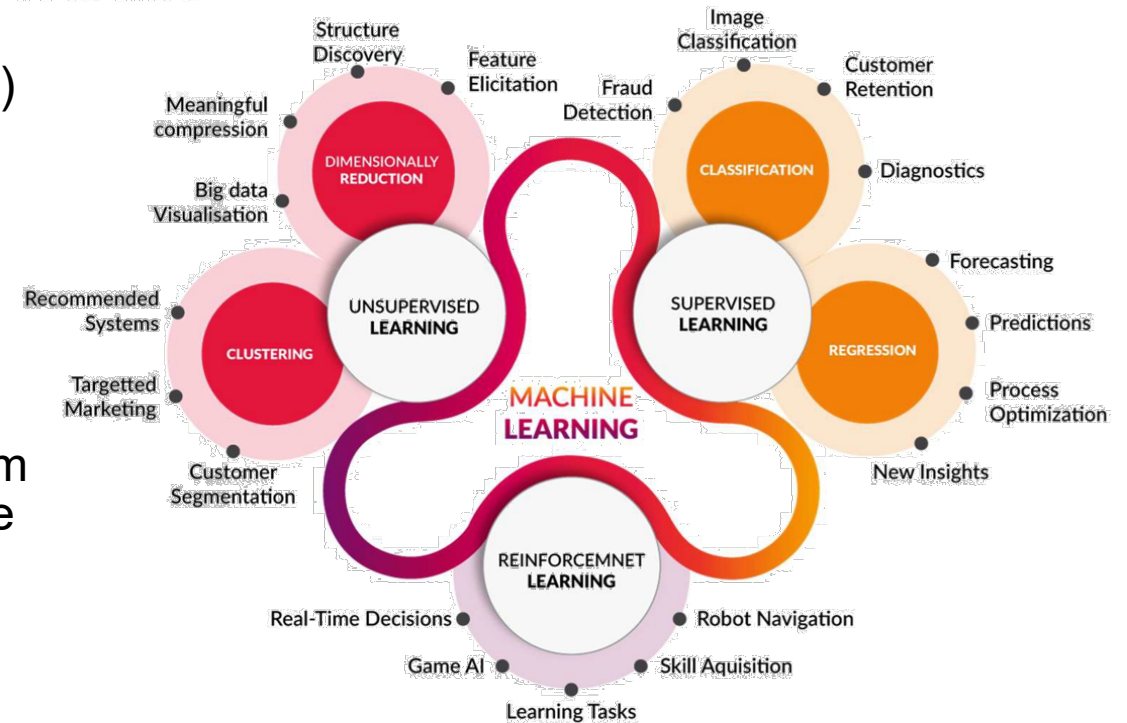


# AI/Machine Learning Symposium Educates Researchers to Promote Collaboration and Engagement

- The Nuclear Safety and Regulatory Research Division sponsored an INL symposium on Artificial Intelligence (AI) and Machine Learning (ML) approaches and activities related to science and engineering.
- Over 200 INL staff participated in the webinar addressing current programs and future applications of this emerging science.



- Activities in the Light Water Reactor Sustainability Program were highlighted through three presentations on automation, predictive maintenance, and nuclear work processes.



Source: <http://www.cognub.com/index.php/cognitive-platform/>



## ***INL Researcher Selected to Join Team Promoting Safe International Uranium Production Activities***

- Dr. Kevin Lyon of the Fuel Cycle Science & Technology Division was selected by the National Nuclear Security Administration to join the Nuclear Compliance Verification (NCV) Uranium Verification Team (UVT).
- In this role, Kevin will work with other team members to verify foreign nuclear material production activities specific to the uranium fuel cycle.



## ***Publications Summary***

- Bragg-Sitton, S., Boardman, R., Rabiti, C., O'Brien, J., "Reimagining Future Energy Systems: Maximizing Energy Utilization via Integrated Nuclear-Renewable Energy Systems," International Journal of Energy Research, February 2020, <https://doi.org/10.1002/er.5207>.
- Kong, F. (2020). "Neutron Transport Criticality Calculations Using a Parallel Monolithic Multilevel Schwarz Preconditioner Together with a Nonlinear Diffusion Acceleration Method." Annals of Nuclear Energy, Vol. 141 (2020).