INL/MIS-22-66551-Revision-0

AFC Newsletter (February 2022)

April 2022

Phyllis L King

Changing the World's Energy Future

Idaho National Laboratory

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

INL/MIS-22-66551-Revision-0

AFC Newsletter (February 2022)

Phyllis L King

April 2022

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

Advanced Fuels Campaign NEWSLETTER

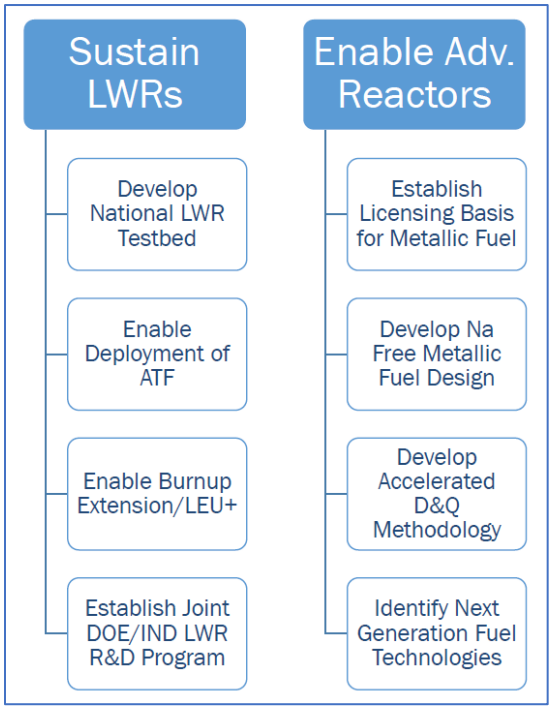
Issue: February 2022

Advanced Fuels Campaign Mission

Conduct R&D on nuclear fuel technology that enables near- and long-term implementation of the reactor systems necessary to meet national nuclear energy objectives.

Overview

The monthly AFC Newsletter provides technical status information from the campaign and is used for a variety of reporting requirements such as briefings to NE-4 and routine internal reporting within our laboratories. Additionally, the newsletter provides a convenient method for communication internal and external to the program. The information is focused on technical accomplishments backed by program execution-type (budget and milestone) information. The technical leads' role in organizing and integrating activities within the AFC Goals (Figure 1) and the impacts of these activities are highlighted each month.



The grand challenge for AFC is to develop and demonstrate transformational technologies in support of the U.S. nuclear industry in the form of high-performance, high-reliability nuclear fuel systems for both current and future reactors.

ATF Lab Activities

ATF Fabrication Properties (Technical Lead: Josh White)

Primary program objectives for FY22 include:

- *Evaluate structure, properties, and performance of accident tolerant fuel systems to improve in-pile performance and performance predictions (ORNL, LANL)*
- *Develop fuel samples with simulated High Burnup Structure (HBS) to enable simplified property assessment (LANL)*
- *Assessment and development of advanced synthesis and fabrication methods applicable to both traditional oxide and high-density nontraditional fuel systems (LANL)*

[LANL] A level 4 milestone report was submitted by Sven Vogel (LANL) and team titled, "Commissioning of a Cask Enabling Characterization of Irradiated Nuclear Fuels with Pulsed Neutrons." Together with collaborators from LANL (E. Larson, V. Mehta, A. Long), INL (J. Angell, A. Craft, B. Gross), ORNL (J. Harp), and UC Berkeley (P. Hosemann), manufacture and initial operation of a proto-type shielding cask that will enable characterization of irradiated fuels with pulsed neutrons was reported. Intense pulsed neutrons sources allow us to probe the entire volume of irradiation capsules to obtain spatially resolved information on phase compositions from diffraction as well as isotope densities and overall densities (e.g., cracks, voids etc.) from energy-resolved neutron imaging and tomography. The latter allows us to also measure the density of fission gases with neutron absorption resonances such as krypton and xenon. Characterizing the entire sample volume will provide more information on normal and abnormal regions that will guide destructive PIE. The cask, named SHERMAN for "Sample Handling Environment for Radioactive Materials Analysis with Neutrons" is designed to shield dose rates up to 900 R/hr, enabling transportation and handling of the fuels, as well as moving the sample in the beam position to enable microstructure scans and tomography. Efforts towards authorization of operation to load fuels at INL are on-going. (S. Vogel)

[LANL/INL] A level 3 milestone report titled, "Characterization of an Irradiated U-1Pd-10Zr Fuel Sample (AFC-3A-R5) with Pulsed Neutrons," was submitted by Sven Vogel (LANL).The report describes characterization of a 6mm diameter, 1.5 mm thick sample cut from an irradiated metallic fuel. Luca Capriotti (INL) and Jason Harp (ORNL) suggested the sample and guided interpretation of the results. An NSUF grant supported shipment from INL to LANL. The dose rate on contact for this sample was 3R/hr, which dropped to 10 mrem/hr at 2 meters, allowing to use remote handling of the sample. The pulsed neutron characterization at LANL provided phase composition as well as using neutron absorption resonances based energy-resolved neutron imaging to determine isotope densities. Consistent with electron-based elemental composition measurements on similar materials, an increase of uranium density towards the outer radius was found, with the neutron-based characterization probing the entire sample rather than much smaller areas on the sample surface. This project was the first neutron characterization of an irradiated fuel sample at the Los Alamos Neutron Science Center (LANSCE). (S. Vogel)

[LANL/ORNL] A publication titled, "The influence of the processing parameters on the reactive flash sintering of ZrO_2-CeO_2," was recently published in the *Journal of the American Ceramic Society* (https://doi.org/10.1111/jace.18426). In this paper the principles for using field assisted sintering, more specifically reactive flash sintering, are outlined. Reactive flash sintering has been investigated to produce mixed oxides, carbides, and nitrides in-situ. ZrO_2-CeO_2 was selected as a surrogate system and the optimized parameters for the in-situ synthesis via reactive flash sintering have been established. (R. Neto, E. Kardoulaki)

ATF Core Materials (Technical Lead: Andy Nelson)

Primary program objectives for FY22 include:

- *Investigate the impact of design and fabrication parameters on Zircaloy coating properties. Activities include production of surrogate test materials, development of novel testing techniques, and characterization of reference materials (LANL, ORNL)*
- *Investigation of the generic materials, application, and evaluation technologies development necessary for cross-cutting development of various SiC/SiC cladding concepts (ORNL, INL).*

Nothing to report this month.

ATF Irradiation Testing (Technical Lead: Nicolas Woolstenhulme)

Primary program objectives for FY22 include:

- *Execution of ATF-2 integral scale irradiations in Advanced Test Reactor (ATR) pressurized water loop (INL)*
- *Separate effects irradiations of advanced cladding and core materials and fuels in the High Flux Isotope Reactor (HFIR) (ORNL)*

[INL] The ATF-2C test is scheduled for insertion into ATR in May of 2022 and will be the first ATF-2 configuration to include instrumentation in fueled pins as well as the first to house SiC clad specimens. Many tasks are currently underway to support this schedule. Recent updates and highlights include kickoff of the final design review, continued fabrication of hardware (which is currently reported as "on schedule" and considered highest priority at INL's machine shops), and preparation of fuel pellets by grinding to the needed dimensions for assembly into instrumented pins (G. Hoggard)

ATF Safety Testing (Technical Lead: Colby Jensen)

Primary program objectives for FY22 include:

- *Participation in the US lead NEA FIDES project on fuel performance under RIA conditions; High Burnup Experiments in Reactivity Initiated Accidents (HERA) irradiation tests (INL)*

- *Execution of out-of-pile fuel safety testing including LOCA-furnace testing and RIA simulation using the modified burst test apparatus (ORNL)*
- *Execute in-pile separate effects fuel safety testing in TREAT with focus on implementation of capsule-based experiments and advanced instrumentation (INL)*
- *Develop and demonstrate new experimental techniques to support fuel safety research including enhanced SATS capability to include fission gas release monitoring capability and development of stress relaxation testing procedure to generate empirical cladding creep data required for prediction of elastic, yield and burst properties of thin wall tubing under transient conditions (ORNL, INL)*

[INL] Fuel was sized and polished allowing the first rodlet for the calibration test in the HERA test series to be built. Additionally, some of the final parts for the capsule build were received, processed, and sent off for material analysis to confirm their qualification for use in TREAT. Drawings for a JAEA test were drafted and are undergoing review. (L. Astle)

[INL] Engineering calculations were performed, checked, and approved to support the shipment of preirradiated fuel from TREAT to HFEF following transient irradiation. Additionally, all personnel and paperwork to support this shipment were arranged. This included a source term calculation and criticality safety evaluation. Metrology work to support the THOR-C-1 and CINDI experiments has been performed as well as modelling work to support LOCA and CHF tests. (L. Astle)

ATF PIE (Technical Lead: Fabiola Cappia)

Primary program objectives for FY22 include:

- *Perform post irradiation examination of ATF-1 and ATF-2 experiments irradiated in the ATR. (INL)*
- *Prepare examination capabilities for full scale ATF lead test rods including enhancement of mechanical testing techniques and recovery of eddy current measurement systems (INL)*
- *Assess microstructural features in high burnup fuel pre- and post-simulated LOCA to improve interpretation of fragmentation behavior (ORNL)*

[INL] The mechanical characterization of anisotropic thin-walled tubes along hoop direction is an important, but non-trivial task. The force-displacement data obtained from ring tension tests depend both on the material mechanical properties and experimental parameters such as friction and fixture compliance. To extract effective material mechanical properties, inverse methods are combined with finite element modeling to separate the tubular material properties from the experimental parameters.

Large-grained Cr2O3-doped UO2 pellets fabricated at Los Alamos National Laboratory are being characterized to understand the sample microstructure before performing commissioning tests on the new STA system installed in IMCL**.** (F. Cappia)

ATF Fuel Performance Assessment (Technical Lead: Pavel Medvedev)

Primary program objectives for FY22 include:

- *Perform analysis of ATF technology as it relates to integral system performance and separate effects behaviors (BNL)*

Nothing to report this month.

Advanced Reactor Fuels

AR Fabrication and Properties (POC: Randy Fielding)

Primary program objectives for FY22 include:

- *Monitor progress and support cross-cutting metal fuel fabrication technology development (INL)*

[LANL] The Level 4 milestone titled, "Update on preparation for fabrication of advanced fuel materials for irradiation testing," was submitted, which detailed an overview of fabrication efforts of advanced fuel materials for accelerated irradiation testing including DISCOVARY program, FAST, and MiniFuel. Demonstrations were shown for each style of accelerated irradiation experiments for several ceramic fuel variants, including UO_2, Cr-doped UO_2, UN, and U_3Si_2. Dimensions ranged from 3 mm to 10 mm in diameter with monolithic or annular geometries. Enrichment handling was authorized up to 27% with custom enrichments per experimental requirements. Fabrication efforts supported Accelerated Fuel Qualification objectives of interest to both industry and DOE-NE Advanced Fuels Campaign. (T. Saleh and J.T. White)

AR Core Materials (POC: Tarik Saleh)

Primary program objectives for FY22 include:

- *Fabrication of advanced fuel materials for irradiation testing of next generation fuel phases (LANL)*
- *Negotiate return of samples irradiated in BOR-60 and the Phenix reactor under collaboration with CEA and TerraPower (LANL)*

Nothing to report this month.

AR Irradiation Testing (Technical Lead: Nicolas Woolstenhulme)

Primary program objectives for FY22 include:

- *Develop accelerated fuel development and qualification methodologies (INL, ORNL, LANL)*
- *Execute FAST-1 accelerated Irradiation tests and PIE in the Advanced Test Reactor (ATR) (INL)*
- *Perform post-irradiation examination of legacy AFC experiments including IRT-1 samples (INL)*

- *Measure thermal conductivity of irradiated metal fuel samples (INL)*

[INL] The FAST-1 outboard-A (OA) capsules represented four of the 28 planned specimens in the FAST-1 group of tests. The OA capsules acted as a control group for the FAST-1 experiments. Assembly was not completed in FY 2021 due to weld failures in the outer capsule seal welds. Due to resource and schedule constraints, the seal weld parameter development using the Weld Under Pressure System (WUPS) is concluded. As such, the welding results remained inconsistent, with weld failures still occurring. These welds remained the greatest threat to on-time assembly completion for the planned four capsule campaign. In February, the FAST-1 project experienced another round of failed WUPS seal welds causing the project to miss the mid-February milestone. One of the four capsules showed satisfactory weld penetration in radiographic inspection. Due to limited remaining parts, schedule, funding, and resource availability, the project is attempting one final round of welding and inspection for the other three capsules to make on-time insertion in the ATR for the 171A-1 irradiation cycle.

All but two FAST-1 capsules remain in ATR canal storage during the ATR CIC outage. Irradiation preparations, including canal configurations and transfer to the vessel will begin at the conclusion of the outage. Preparations for work cycle analyses is on-going.

PIE work in HFEF is on-going. JFCS AFC-IRT-1 C3 and C4 gamma scanning has been completed, and specimens are in storage. The JFCS closeout report has been completed. AFC-3F and AFC-4C capsules are in storage. However, advanced characterization of the AFC-4C R5 is now in planning. FAST-1 NRAD and gamma scanning has been completed. Profilometry is planned to start in March. (C. Murdock)

[INL] The Level 3 milestone report titled, "Report on Results for Thermal Conductivity of Irradiated U-10Zr Fuels," was completed (INL/RPT-22-66239). This report summarized the local thermal conductivity measurements taken on three samples of irradiated U-10Zr fuel from the MFF3 experiment (pins #193114 and 193045) at FFTF and one sample from AFC-3A experiment conducted at ATR. The MFF3 samples used in this study are given in the table below.

Sample ID	Irradiation Test	Sampling position*	Centerline Temperature	PICT+	Burnup
MNT-54C	FFTF MFF3 pin# 193114	0.50	675 °C	550 °C	12% HM burnup
MNT-44Z	FFTF MFF3 pin# 193114	0.30	630 °C	475 °C	11% HM burnup
MNT-83T	FFTF MFF3 pin# 193045	0.98	675 °C	615 °C	5.7% HM burnup

Table 1. MFF3 samples used in study.

The following figure shows a comparison of thermal conductivity and thermal diffusivity between the samples from the MFF3 experiment. The trendlines are only to assist the eye in following the data and may not be a true representation of the data trends as a function of

radial position. It is interesting to note that the two samples at the higher positions on the fuel pin have lower thermal property values. A sample of fresh U-10Zr from the same fabrication batch as the MFF3 experiment material is included in the comparison. (C. Adkins)

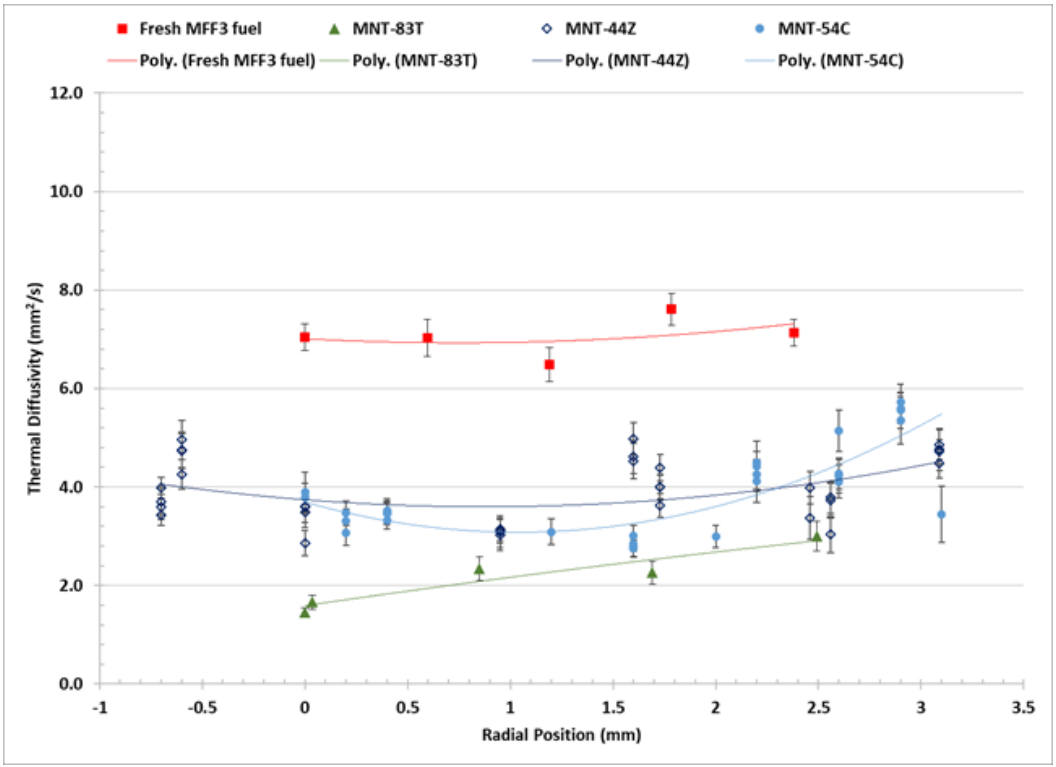


Figure 1. Thermal Diffusivity vs. Radial Position for Irradiated U-10Zr.

AR Safety Testing (Technical Lead: Colby Jensen)

Primary program objectives for FY22 include:

- *Execute joint JAEA/INL ARES fuel safety research experiments on commissioning TREAT sodium capsule testing n fresh metallic fuels (THOR-c) and transient testing historically irradiated metal (THOR-M) and MOX (THOR-MOXTOP) fuels (INL)*

[INL] The THOR-C-2 capsule has been assembled and is ready for insertion. Pre-characterization of the JAEA MOX pins at HFEF has begun and preliminary results have been shared with JAEA. JAEA is pleased with the characterization results and investigating the possibility of future projects using the THOR capsule.

The THOR-M final design review has been closed and recorded.

The HFEF THOR team has made better than expected progress on the design and preparation of HFEF to handle a THOR capsule. Fabrication of the handling fixtures has begun. (T. Smuin)

Capability Development

I-Loop Design and Installation (POC: Nate Oldham)

[INL] Work package is on hold. (L. Strain)

TREAT LOCA Testing Infrastructure (POC: Nicolas Woolstenhulme)

Primary program objectives for FY22 include:

- *Design and installation of i-loop system components (INL)*
- *Development and commissioning of TREAT LOCA-capsule (INL)*
- *Development and commissioning of remote refabrication and instrumentation capability (INL)*

[INL] Out-of-pile prototype hydrostatic testing was completed which allowed for the laboratory instructions to be drafted and put out for SME review. Final design progress continued with several key instrument changes and some programmatic analysis for temperature and pressure conditions for various reactor transients to be analyzed. (L. Astle)

Refabrication and Instrumentation Capability (POC: Jason Schulthess)

[INL] Comments on the lab Instructions needed to operate the welding module obtained from the Halden Reactor project were incorporated.

1. Lab Instructions needed to operate the welding module were approved and we completed equipment checkout of the major functions of the module.
2. Performed several in air welding practice runs followed by a butt weld with the chamber closed and filled with inert gas. This first weld performed inside the chamber looked surprisingly good – full penetration around the full 360 degrees.

As part of the refabrication scope last fiscal year, fabrication of a second Rodlet Endcap Welding system to be used outside of a hot cell environment was completed. This second system is in the process of being set up in the AFF facility at MFC and a few necessary modifications to the facility were completed.

A conceptual design document was developed for focusing on thermocouples attached to rodlets and a preliminary design was developed as a holding fixture for attaching thermocouples to rodlets on previously irradiated fuel. Initial prototyping and design refinement is beginning. The use of cryogenic liquids was evaluated by relevant HFEF operations and safety personnel and determined that there are no critical impediments to installing a cryogenic based drilling system. Additional evaluations are ongoing to identify the full scope and develop order of magnitude cost estimates for designing and installing a cryogenic drilling equipment evaluation for HFEF. (M. Cole)

FOA Support

Framatome (Kiran Nimishakavi)

Nothing to report this month.

General Electric (Raul Rebak)

In February, GE ended Budget Period 1 of contract DE-NE0009047 working on developing two main concepts of cladding for ATF as well as studying the viability of HBU and higher U235 enrichment.

GE has been working closely with national laboratories. INL completed ARMOR rodlets studies removed from the ATR in June 2021. Currently, INL is preparing testing in the i-loop and performing welding trials of IronClad for incoming ATF-2 testing. LANL is developing fuel for GE focused on additions of uranium carbide to the basic Urania fuel. ORNL has ended the PIE studies of ARMOR removed from Hatch NPS#1 and is focusing on PIE studies of IronClad.

A publication titled, "Zinc water chemistry reduces dissolution of FeCrAl for nuclear fuel cladding" by R. B. Rebak, T. B. Jurewicz, M. Larsen and L. Yin, was published in Corrosion Science, 198 (2022) 110156.

Westinghouse Electric Company (Ed Lahoda)

Westinghouse continued meetings with utilities to align dates and requirements for future lead test assemblies (LTAs). Work continued with the building of the lead test assemblies for various plants.

Input was provided to the U.S. DOE on ramp test needs. Post Irradiation examinations proceeded at ORNL on the ATF rods discharged from the Byron 2 first cycle.

Silicon Carbide Cladding (FOA)

General Atomics (Ryan Hon)

Nothing to report this month.

Documents

Articles

[The Need For a Metallic Nuclear Fuels Qualification Plan, Nuclear News]

Publications

- Kun Yang, Erofili Kardoulaki, Dong Zhao, Bowen Gong, Andre Broussard, Kathryn Metzger, Joshua T. White, Michael R. Sivack, Kenneth J. Mcclellan, Edward J. Lahoda, Jie Lian, Cr-incorporated uranium nitride composite fuels with enhanced mechanical performance and oxidation resistance, Journal of Nuclear Materials, Volume 559, 2022, 153486, ISSN 0022-3115, https://doi.org/10.1016/j.jnucmat.2021.153486.
- Rubens Roberto Ingraci Neto, Erofili Kardoulaki, James Anthony Valdez, The influence of the processing parameters on the reactive flash sintering of ZrO_2-CeO_2, Journal of the American Ceramic Society, 2022, https://doi.org/10.1111/jace.18426
- R. B. Rebak, T. B. Jurewicz, M. Larsen and L. Yin, Zinc water chemistry reduces dissolution of FeCrAl for nuclear fuel cladding, Corrosion Science, 198, 2022, https://doi.org/10.1016/j.corsci.2022.110156
- FY21 AFC Accomplishments Report
- AFC Newsletter – January Issue
- AFC Newsletter – December Issue

Milestones

Level	WP Number	WP Title	Site	Id No.	MS Title	Estimated Finish	Revised Finish
M2	FT-22IN02030401	ARES - joint work with JAEA to study off-normal behavior of fast reactor fuels - INL	INL	M2FT-22IN0203040115	Conduct Preliminary Design Review for THOR Remote Handling and Process Equipment	2/15/2022	
M3	FT-22IN02030301	AF Irradiation Testing - INL	INL	M3FT-22IN020303011	FAST-1 OA Assembly Complete	2/15/2022	4/15/2022

AFC SharePoint Site

[Advanced Fuels Campaign SharePoint site]

Look Ahead

March

- (ORNL) Initiate destructive examination of WEC lead test rods
- NRC Regulatory Information Conference (RIC), March 8-10 (virtual)
- Joint EPRI-DOE ATF/HBU/ CRAFT Workshop, March 28-April 1 (Charlotte, NC)
- (INL) Complete ARES project CRADA deliverable for pre-transient characterization of MOX pins

April

- FIDES Technical Advisory Committee and Governing Board Meetings, April 25-29 (Paris, France)
- (INL) ATR startup after completing CIC
- AFC Leads Planning Meeting, April 6-7 (Idaho Falls, ID)
- International Conference on Fast Reactors and Related Fuel Cycles: Sustainable Clean Energy for the Future (FR22), April 17-24 (Vienna, Austria)

May

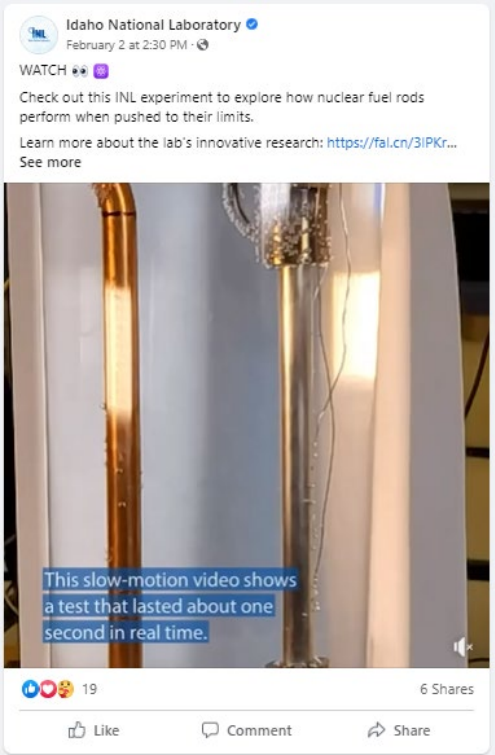
- (INL) Commence FIDES HERA JEEP experiment calibration tests in TREAT
- Materials Research Society (MRS) Annual Meeting, May 9-16 (Honolulu, HI)
- NETS 2022, May8-12 (Cleveland, OH)
- DEVICE MTR Meeting, May 10-13 (Richland, WA)
- PHYSOR 2022, May 15-20 (Pittsburgh, PA)
- (INL) Continues THOR-C commissioning testing

June

- VTR Experiments Meeting, June 7 (Oregon State University)
- ANS National Meeting, June 12-16 (Anaheim, CA)
- FIDES/HERA Workshop, June 21-23 (Idaho Falls, ID)
- (INL) Continue FIDES HERA JEEP experiment Zr-4 cladding test in TREAT
- (INL) Continues THOR-C commissioning testing

Social Media

Facebook

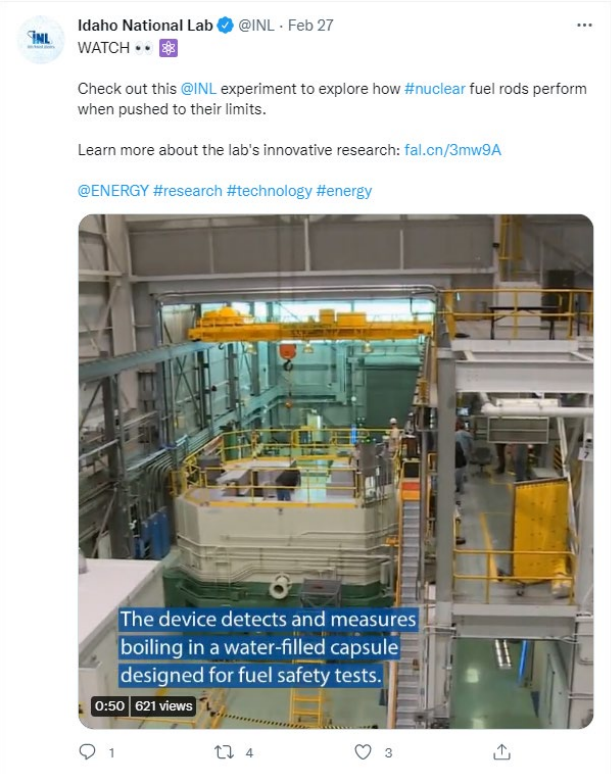


https://www.facebook.com/IdahoNationalLaboratory/videos/inl-treat-facility-experiment/732511171047039/

Twitter

https://twitter.com/INL/status/1491177540358062083

https://twitter.com/i/status/1495108512338395140



https://twitter.com/i/status/1498032769435381764

LinkedIn

https://www.linkedin.com/posts/idaho-national-laboratory_inl-treat-facility-experiment-activity-6898755229144219648-SSH0