INL/EXT-21-63734

Nuclear Fuel Cycle and Supply Chain (NFCSC) Technical Monthly May FY-21

May 2021

Changing the World's Energy Future

Idaho National Laboratory

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Idaho National Laboratory
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Nuclear Fuel Cycle and Supply Chain (NFCSC) Technical Monthly May FY-21

1. ADVANCED FUELS CAMPAIGN (AFC)

1.1 Industry FOA

1.1.1 Westinghouse ATF FOA

[INL] Experiment redesign continued, designated ATF-2C, which will consist of four tiers. The bottom tier (Tier 1) will include SiC clad pins with surrogate Mo/W fuel pellets, Tier 2 will include Framatome pins, Tier 3 will include SiC clad pins with surrogate Mo/W fuel pellets, and the top tier (Tier 4) will be Zr-4 clad UO_2 pins, with temperature and pressure sensors. Installation of ATF-2C is planned for the Cycle 171A outage during the third quarter of FY-22. (G. Hoggard)

[ORNL] Development of SiC fiber–reinforced SiC matrix composite continues for use in accident-tolerant fuel cladding for light water reactors because of its inherent advantages of low neutron absorption, irradiation resistance, and high-temperature capability. Current composite designs include an outer monolithic SiC layer, in part, to increase steam oxidation resistance in a loss-off coolant accident scenario. However, it is not clear how the cladding behaves under high-temperature steam if the monolithic layer cracks, carbon interphases, and SiC fibers are exposed. To fill the knowledge gap, this work is aimed at understanding the stress corrosion cracking behavior under steam oxidation. During this period, we have developed a testing system designed for tensile testing of a prototypic SiC composite tube segment at up to 1000°C with 100 % steam at atmospheric pressure (Figure 1). It consists of a specialized quartz environmental chamber and sealing mechanism at the grips. This is a unique capability to test SiC cladding under simulated LWR accident environments. (T. Koyanagi, C.S. Hawkins, O. Karakoc, Y. Katoh, E. Lara-Curzio)

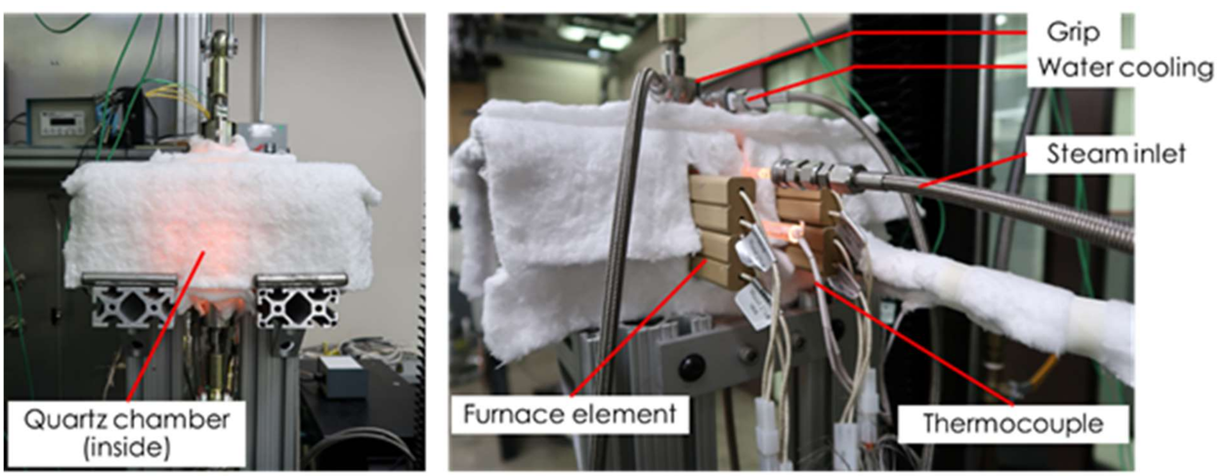

Figure 1. Appearance of test system for tensile testing of a prototypic SiC composite tube segment at up to 1000°C with 100% steam at atmospheric pressure.

1.1.2 Framatome ATF FOA

[INL] ATF-2 was removed from the Advanced Test Reactor and moved to the canal. General Electric boiling water reactor type pins were removed from their holders and visually inspected in the canal. A shipment of ~23 irradiated pins to the Hot Fuel Examination Facility is scheduled for September 14, 2021. (G. Hoggard)

1.1.3 GE ATF FOA

[LANL] The scope for Phase 2B work was completed and consisted of the down selection of advanced fuel concepts and initial investigations of selected fuels. The fuels consisted of UO_2 based composites, and included studies of fabricability, sinterability, and chemical compatibility between matrix and particulate phases. The findings at the close of Phase 2B work show promising results for UO_2 composite fuels as drop-in replacement for UO_2 fuels. Further investigations of corrosion resistance and chemical compatibility with cladding material will be carried out under the Phase 2C funding cycle. (S. Paisner, J. White)

1.2 ATF Lab Activities

1.2.1 ATF Fabrication Properties

[LANL] The publication titled, "High temperature mechanical properties of fluorite crystal structured materials (CeO_2, ThO_2, and UO_2) and advanced accident tolerant fuels (U_3Si_2, UN, and UB_2)," has been published in the *Journal of Nuclear Materials*. The manuscript details the mechanical interaction between the fuel and cladding that occurs during operation of a nuclear reactor, which is important to understand as it can lead to cladding failures and release of radioactive material into the coolant. In order to develop better models of pellet-cladding mechanical interactions when accident tolerant fuel candidates are used, the mechanical properties of the fuel at relevant operating temperatures, like the elastic moduli, are needed for current and advanced accident tolerant fuels (ATFs). In this work, elevated temperature nanoindentation and resonant ultrasound spectroscopy were used to measure the moduli and hardness of several fluorite materials (CeO_2, ThO_2, UO_2) and several ATF candidates (ATF) (U_3Si_2, UN, UB_2). In addition, a comparison of the two techniques was performed in this study to independently validate the mechanical properties. (J. White)

The publication titled, "Instability of U_3Si_2 in pressurized water media at elevated temperatures," has been published in *Communications Chemistry*. In this contribution, we report the results of experiments investigating the stability of U_3Si_2 in pressurized water at elevated temperatures and identify the mechanisms that control the interaction of U_3Si_2 under these conditions. Our data indicate that the stability of this material is primarily controlled by the formation of a layer of $USiO_4$ (the mineral, coffinite) at the surface of U_3Si_2. The results also show that these layers are destabilized at $T > 300$ °C, leading to the complete decomposition of U_3Si_2 and its pulverization due to its full oxidation to UO_2. (J. White)

[LANL] The first pellets made with UO_2 nanopowder (~30 nm) were sintered via flash sintering and were characterized. Significant mass losses were observed during the sintering process and later confirmed by thermogravimetric analysis. As a result, the pellets were not densified above 6.57 g/cm^3. SEM images of the cross sections of the pellets revealed the formation of tenths of micron long crystalline structures, similar to those obtained from flux crystal growth. These observations led to the hypothesis that the UO_2 nanopowder is likely contaminated with a hydroxide from the synthesis process, which would not appear on the powder XRD. The exact nature of the contamination needs to be determined so that extra steps on the nanopowder synthesis process can remove it. Fine control of the synthesis and sintering steps are essential for obtaining nanograin microstructures to simulate high burnup structures. (R. Ingraci, E. Kardoulaki)

1.2.2 ATF Core Materials

[LANL] Microscale mechanical tests were performed on Zircaloy clad through a cold spray process (U. Wisconsin) as well as Zircaloy clad through magnetron sputtering (HiPIMS). Data analysis is underway. (S. Maloy)

1.2.3 ATF Irradiation Testing

[INL] Development of ATF-2C hardware and instrumentation design and fuel pin fabrication continued. (G. Hoggard)

[INL] Mechanical property characterization tests generate data that are needed for inputs to fuel performance modeling and could be used to support a fuel qualification report. Testing of irradiated Axial Tension Specimens from irradiated Zircaloy cladding harvested from ATF-2 reference rods was completed. Data was analyzed to determine the yield stress, tensile stress and uniform elongation in the sample. Load-displacements curves are shown in Figure 2. A picture of the fractured specimen at the end of the test is shown in Figure 2. The process was qualified following NQA-1 requirements and can proceed with irradiated ATF claddings this fall. (F. Cappia)

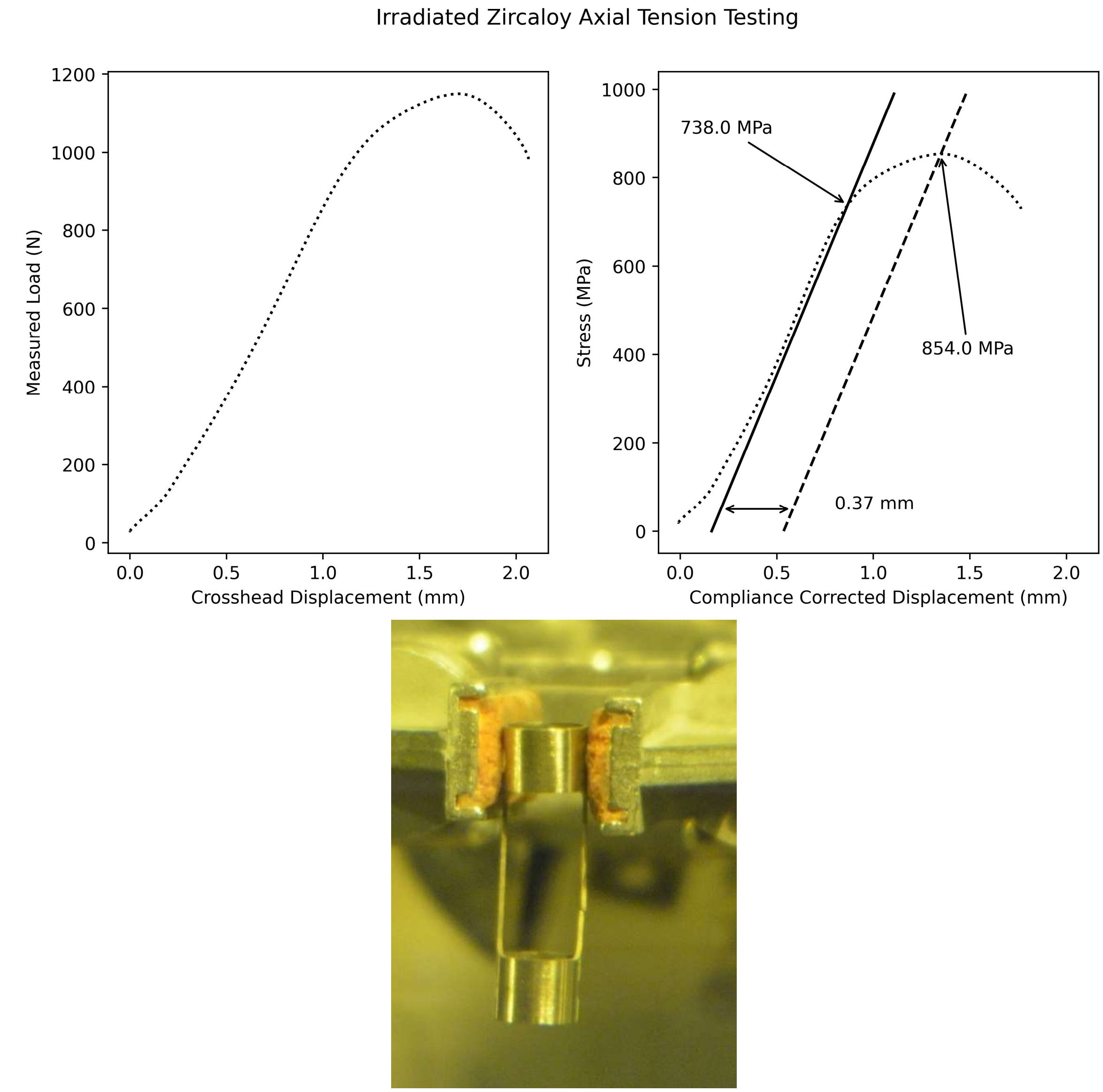

Figure 2. Photo of the fractured specimen and load displacement curves.

[ORNL] A RELAP5-3D model of the MiniFuel basket in a Removable Beryllium (RB) position of the HFIR was developed to aid in thermal hydraulic design and safety analysis. A script was developed to automatically vary the geometry of the current basket design within expected dimensional tolerances and regenerate the RELAP5 input deck. This methodology allows for rapid sensitivity analysis that can predict a range of potential hydraulic conditions in HFIR to ensure safety requirements are met for the entire range of geometric tolerances. Potential design changes to the basket can easily be accommodated in the sensitivity analysis script. Results from the script will also be used to provide boundary conditions for a finite-element model of a single target in ANSYS. (Gorton, Petrie)

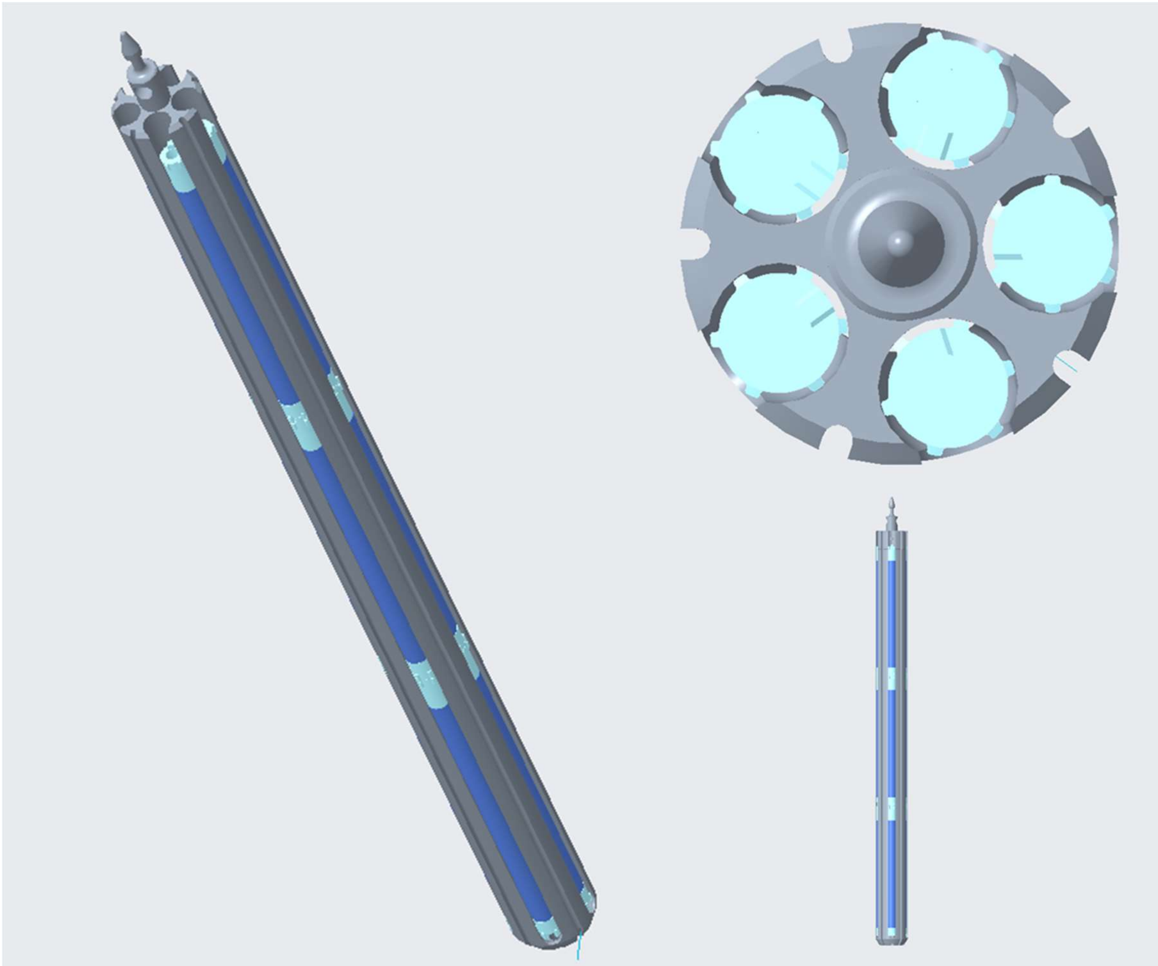

Figure 3. Conceptual MiniFuel RB Basket Design.

1.2.4 ATF Safety Testing

[INL] All procurements and fabrication work requests are in place for the TWIST Prototype testing rig and fabrication has commenced. (D. Dempsey)

[INL] Conducted gamma spec on accident tolerant fuel (ATF)-reactivity initiated accident (RIA) fuel pin counting in the basement of the analytical lab. (T. Pavey)

[INL] All work associated with the TREAT Experiment Gas Supply and Leak Testing Equipment was completed. The MARCH-SERTTA Instrumentation Verification System was completed. HFEF In-cell Loading/Leak Testing Procedure validation is complete. TREAT and HFEF MSA/CRA was completed for re-authorization of the 15-Cask. All work was completed to support the loading of ATF-R in HFEF and subsequent shipment to TREAT for irradiation. (M. Bybee)

[INL] The mechanical design of the project was finalized, allowing drawings for the experiment to be drafted. Drawings are undergoing checks currently. Additionally, the initial neutronics and thermal calculations and analysis reports have been assembled. Mock-up parts were received / fabricated and are expected to be assembled in the very near future. (L. Astle)

[INL] The mechanical design of the project was finalized, allowing drawings for the experiment to be drafted. Drawings are undergoing checks currently. Additionally, the initial neutronics and thermal calculations and analysis reports have been assembled. Mock-up parts were received / fabricated and are expected to be assembled in the very near future. (L. Astle)

[ORNL] The Level 3 milestone M3FT-21OR020204074, "High-Temperature Steam Oxidation of Irradiated FeCrAl in the Severe Accident Test Station," was successfully completed. The ATF-18 rodlet was one of three first-of-a-kind FeCrAl-UO2 test capsules fabricated at ORNL and irradiated at the INL-Advanced Test Reactor. Following irradiation, samples were sectioned from the irradiated rod and oxidation kinetics were evaluated to access the candidate cladding high-temperature oxidation performance following irradiation. The irradiation was performed at approximately 400ºC to a burnup of 10 GWd/MT. The high-temperature oxidation tests were conducted in the ORNL Severe Accident Test Station (SATS) at 1200 and 1300ºC.

The oxygen pickup of irradiated C35MN FeCrAl was low at 1200ºC (Figure 4) while the irradiated test samples heated to 1300ºC (Figure 5) oxidized within the first minute at the target temperature. This phenomenon was not observed for unirradiated ATF-18 surrogate specimens oxidized in steam at 1300ºC up to 240 min. More testing and characterization will be required to understand the mechanism of enhanced oxidation at 1300ºC. (Y. Yan, K. Linton, J. M. Harp)

Figure 4. Post-test images of irradiated ATF-18 specimens oxidized at 1200°C.

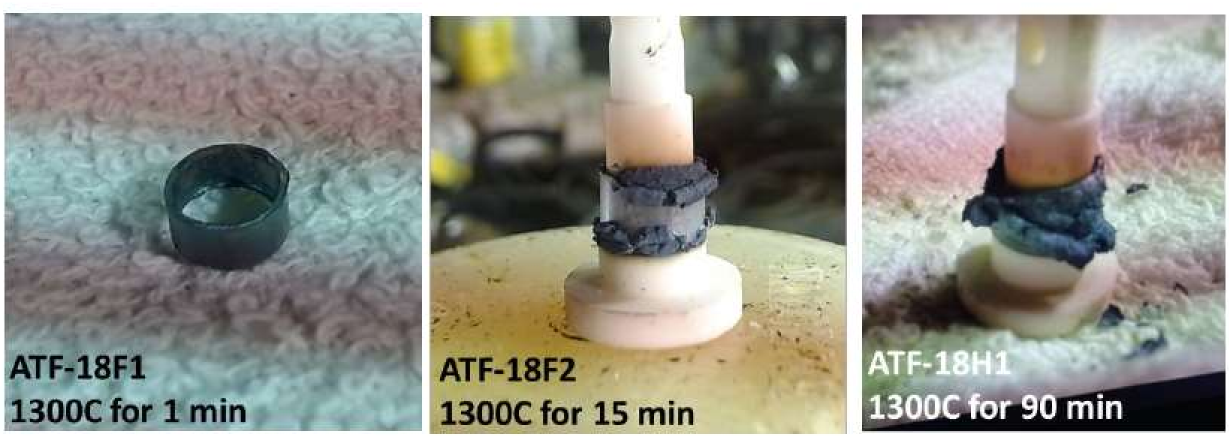

Figure 5. Post-test images of irradiated ATF-18 specimens oxidized at 1300° C.

1.2.5 ATF Performance Assessment

[BNL] The TRITON lattice code model for a reference 17x17 Westinghouse fuel assembly is being modified to incorporate potential ATF fuels that are composites of UO_2-UB_2 and composites of UN fuels, e.g., UN-UB_2, UN-CrN and UN-AlN. Consistent with previous analyses examining the impact of advance fuels on reactor performance and safety characteristics, discharge burnup and cycle length along with fuel and moderator temperature reactivity coefficients and control coefficients (soluble boron and control rods) will be estimated. Calculations are underway. (M. Todosow)

1.3 Advanced Reactor Fuels

1.3.1 AR Fabrication and Properties

[**INL]** The potential irradiation test matrix and fabrication schedule was coordinated with LANL and ORNL. Gaps in fuel behavior data were identified for the proposed fuels in matrix. Discussed general irradiation test design, sample dimensions, irradiation test schedule, deliverables, and quality assurance with EPRI. (M. Meyer)

1.3.2 AR Irradiation Testing

[INL] FAST-1 assembly recovery work will continue for the outboard-A group of capsules as resources become available this summer. Fabrication of parts used for recovery efforts are in process with an anticipated June finish.

The 169A-1 ATR irradiation cycle is concluded. All AFC-OA, except two AFC-4D and two AFC-IRT1 capsules have now met burnup targets and await shipment to HFEF for PIE and/or storage. Two FAST-1 capsules also met burnup targets and await shipment to HFEF for PIE. The remaining FAST-1 capsules will remain in ATR canal storage for the duration of the ATR Core-Internals Changeout (CIC). Destructive examinations of the AFC-4C (C5) are planned to continue in June. FAST PIE preparations in-cell are expected to conclude early June (C. Murdock)

[INL] Interested metallic fuel pins in HFEF for pre-transient PIE have been identified and characterization has started. Another set of metallic fuel pins has been identified in RSWF to be shipped back to HFEF in the third quarter of 2021. Furthermore, irradiated samples have been selected from the CINDI TREAT experiment, for possible destructive analysis to continue some separate effect testing on metallic fuel undergone transient and from already irradiated (TREAT transient) U-metal.

Gamma spectroscopy and neutron radiography was completed on three metallic fuel pins in HFEF. The 3 pins are: X429-T609 (ternary), X430A-T679&T681 (binary). Those pins will conclude non-destructive examinations prior to be used in TREAT experiment. (L. Capriotti)

[INL] May focused on writing / revising publications and continuing the draft milestone report for this project. Data analysis on the most recent thermal conductivity microscope data continues. Additionally, a draft for a review paper in collaboration with NEAMS on irradiated U-Zr models for thermal conductivity was started. (C. Adkins)

[INL] The kickoff meeting for the sodium loop commissioning experiment design was completed and initial assignments made for the work. (T. Pavey)

1.3.3 AR Safety Testing

[INL] Capsule fabrication for THOR testing is progressing, we are waiting for a final part to complete fabrication of the first batch of capsules. The THOR project team completed fabrication of a THOR capsule mockup. It has proven to be effective for visualizing the capsule in gloveboxes for assembly. The THOR project team is currently testing and perfecting the procedure of sodium bonding within the THOR capsule inside of a glovebox. The RSWF fuel retrieval team completed the transfer of legacy MOX pins to FCF, which is a huge success for the project team. (T. Smuin)

1.4 High Burnup Fuels

1.4.1 HB TREAT Testing Infrastructure

[INL] The Davis-Bacon determination was completed and ruled as “non-covered” work. All shield plate drawings were completed. Completed fabrication of shield plates. Phase I and II qualification for the mill began. Materials were ordered and fabrication began of backup cables. (M. Cole)

[INL] Fabrication of the Rodlet End Welding System (REWS) is 80% complete. Worked on epoxying pellets into the cladding surface and drilling multiple pellets. Continued designing/building configurations of rodlets with centerline thermocouples. Continued working on the EPIC System design. (M. Cole)

1.4.2 HB Halden Gap Activities (I-Loop)

[INL] The loop flow diagram was completed. Conceptual neutronics calculations were completed. Multiple conceptual design activities kicked off with the integrated NS&T and ATR design engineering team. (L. Strain)

[INL] The Top Head Closure Plate (THCP) lift cart, track system, and top head stand were received at ATR on May 13 (baseline delivery date May 26). Assembly of the top head stand, lift cart, and track system in ATR-670 was completed on May 26. Vendor personnel responsible for THCP removal and installation have been identified and initial training completed. Multiple preliminary design activities were started. (L. Strain)

[INL] The ATR-C Run is complete. Final model analysis is being updated for actual conditions during experiment. (J. Johnson)

[INL] Test train conditions have been identified. Conceptual design is underway. (J. Johnson)

For more information on Fuels contact Steven Hayes (208) 526-7255.

2. MATERIAL RECOVERY AND WASTE FORMS DEVELOPMENT

2.1 Aqueous Chemistry

[ANL] Activities have been shifted to Aqueous Separation Science & Novel Processes - ANL (C. Pereira)

[INL] The INL, in collaboration with several European Union research institutions, is participating in a round-robin evaluation of the radiolytic stability of the GENIORS process solvent used for An/Ln recovery from dissolved used nuclear fuel raffinate. The INL Radiolysis Test Loop is one of three irradiation facilities utilized in this evaluation. The Test Loop irradiation of the GENIORS solvent was recently completed. Aqueous and organic samples were removed from the Test Loop as a function of absorbed gamma dose. Batch contact flowsheet tests to determine the impact of gamma radiolysis on the performance of the GENIORS process solvent are ongoing. Preliminary results from the batch contact flowsheet tests indicate significant degradation of the dimethyl-N,N,N',N'-tetradecyl-diglycolamide (cis-mTDDGA) extractant occurs, but the ability of the solvent to selectively separate americium from the trivalent lanthanides is maintained. Further analyses to determine solvent composition versus absorbed gamma dose and to identify cis-mTDDGA radiolytic degradation products are planned.

A trip was completed to Brookhaven National Laboratory, during which time-resolved uranium loaded TBP, DEHBA, and DEHiBA n-dodecane radical cation pulsed electron experiments were performed to support Milestone M3FT-21IN030101026 "Effect of Metal Ion Complexation on the Radiolysis of TBP and Monoamide Extractants" and additional experiments for the reaction of CDTA, AHA, and HA with eaq–, H, OH, and NO3 were also performed to support model development for Milestone M3FT-21IN030101025 "Radiolytic Evaluation of CDTA and AHA Additives". (G.P. Horne)

A presentation was made at the Actinide Separations Conference 2021. The material presented covered both experimental and computational progress for Milestone M3FT-21IN030101025 "Radiolytic Evaluation of CDTA and AHA Additives". (G.P. Horne)

A new Science Undergraduate Laboratory Internships (SULI) student (Rachel Umpleby) has joined the research team. Rachel will be assisting us with steady-state gamma irradiations of biphasic AHA solutions – contacted with organic phases comprising TBP, DEHBA, or DEHiBA in n-dodecane – in support of Milestone M3FT-21IN030101025 "Radiolytic Evaluation of CDTA and AHA Additives". (G.P. Horne)

A book chapter was prepared in support of milestone FT-21IN03010102 entitled "Aminopolycarboxylates in Trivalent f Element Separations" was authored by Peter R. Zalupski, Travis S. Grimes, Corey D. Pilgrim and Colt R. Heathman from INL, as well as Santa Jansone-Popova, Katherine R. Johnson, Vyacheslav Bryantsev and Robert C. Chapleski, Jr. from ORNL. (D. Wood)

[ORNL] During the past month, we finalized and submitted our paper on Ln(III)/An(III) separations with phosphinic acids. Our calculations focusing on separation of trivalent lanthanides and actinides with octapa have also progressed. We have nearly completed geometry optimization, frequency, and solvation energy calculations of ligand- and solvation-complexes with several f-group elements using a density functional for which the literature on aminopolycarboxylic acids and our previous work on phosphinic acids has shown promise in terms of structure and selectivity. We continue to work with another, more commonly used DFT treatment for benchmarking purposes. Over the next month, we will continue with these calculations and move on to post-Hartree-Fock selectivity calculations. (V. S. Bryantsev)

The synthesis of pypa-based aqueous complexant with improved hydrophilicity has been completed in 5 steps. 1.5 g of this compound have been shipped to INL for further testing. The aqueous-soluble 1,10-phenanthroline-based ligand (aqueous complexant/holdback agent) shows excellent performance in Am(III)/Eu(III) separation with distribution ratios for Am being bellow 1 and distribution ratios for Eu being significantly above 100 – leading to excellent selectivity in Eu/Am separation (> 500) even at 2 M nitric acid concentration. These results were presented on May 19 during the Actinide Separations Conference. Title of the talk "Novel Preorganized Ligands for Selective Actinide and Lanthanide Separation". (S. Jansone-Popova)

2.2 Waste Forms

[PNNL] Supported the UK/US technical exchange on off-gas capture and presented iodine waste forms at the MRWFD spring meeting. (M. Asmussen)

Fluoride waste forms were fabricated using a TeO_2 or TeO_2-GeO_2 glass-forming system with a NaF-LiF-NdF_3 (65.9%-28.6%-5.4% by mass) salt simulant. For the TeO_2-GeO_2 glasses, an 80-20 or 70-30 mass ratio was used, respectively, and is denoted in the first part of the glass label whereas the second part (e.g., 10%) denotes the mass loading of the fluoride salt simulant. The samples appeared an orange-tan color with glassy surfaces at the lower salt loadings and with noticeable phase separation or crystallization in the higher loadings (see Figure 6). Based on X-ray diffraction (XRD), scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) analysis on these different materials in polished cross sections, it is clear that the alkali fluorides incorporate into the glass in part while some alkali fluorides and $NdNaF_4$ phases separated out during cooling into small droplets and other structures (see Figure 7). Samples were shipped to ANL for chemical durability measurements to assess material performances and to guide future glass formulation efforts. (B. Riley)

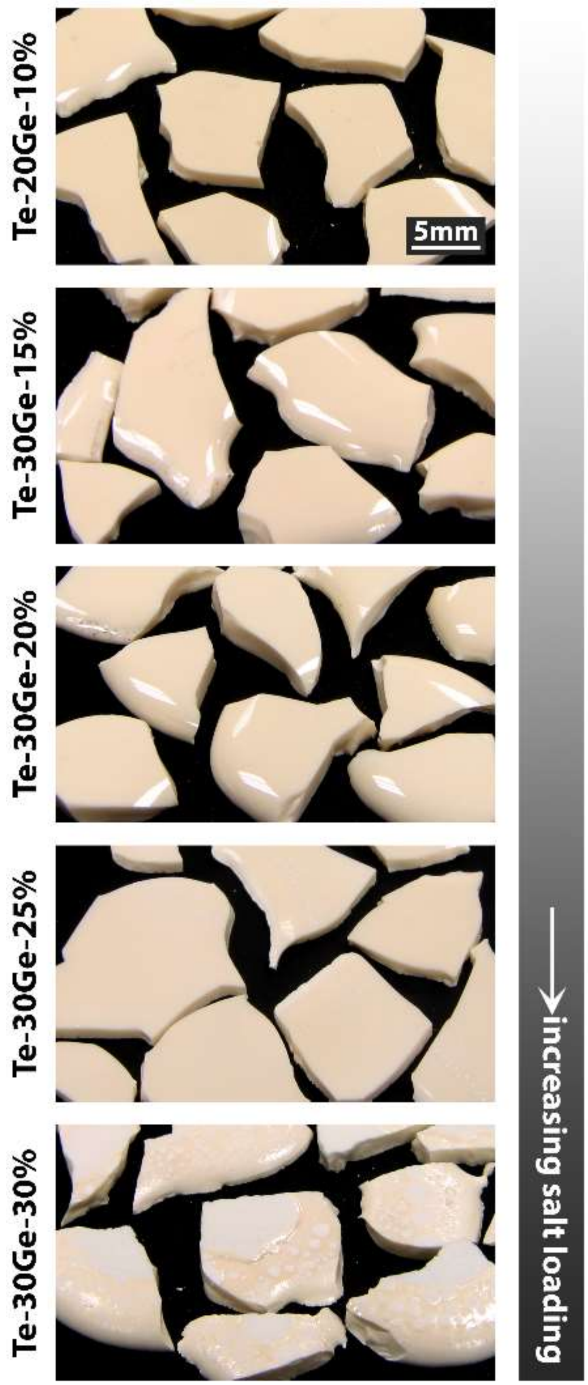

Figure 6. Optical appearances of TeO_2-GeO_2 glasses containing the fluoride salt simulant.

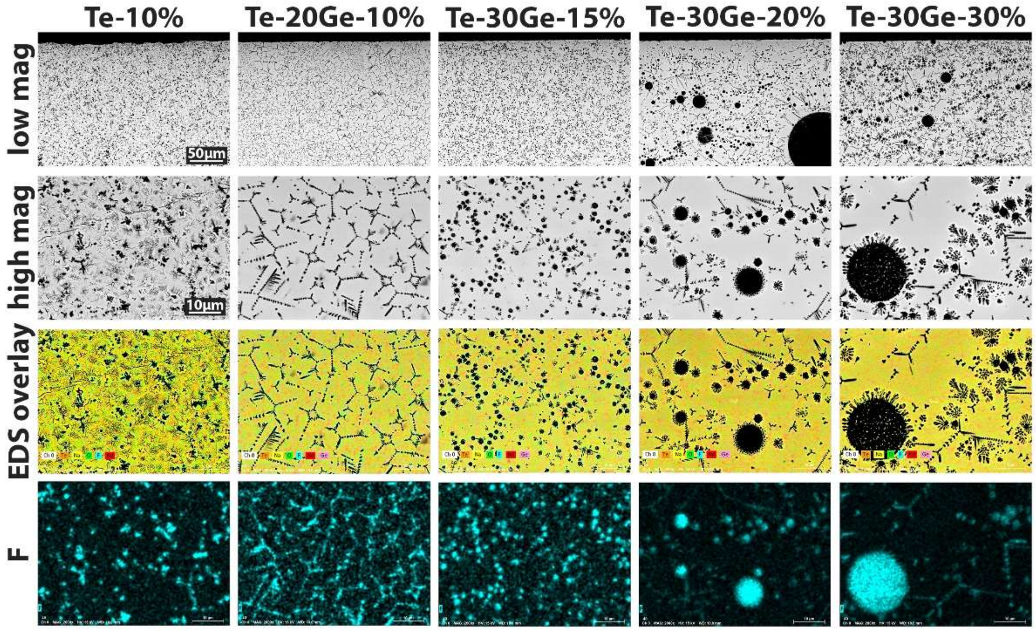

Figure 7. SEM-EDS collage of fluoride salt waste forms produced at PNNL. These are either TeO_2 (i.e., Te-10%) or TeO_2-GeO_2 (i.e., all but Te-10%) glasses containing various loadings of NaF-LiF-NdF_3 salt simulants at 10–30 mass% (value at end of glass ID).

2.3 Off-Gas Capture

[INL] The iodine adsorption test that was started on April 28 was ended on May 14, 2021. This test emulated a dissolver offgas stream, with an average of about 25 ppmv elemental iodine (I_2), 1.5 vol% H_2O (moisture dewpoint of about 11 degrees C), 800 ppmv each NO and NO_2, and balance air. The sorbent is AgZ-PAN. The test ran about 212 hours. Gas and bed samples from five bed segments were collected periodically for analysis to determine iodine capture efficiency, AgZ-PAN capacity for iodine, and the mass transfer zone, as the test progressed.

Nick Soelberg and Amy Welty attended the virtual MRWFD Campaign virtual spring meeting held on May 11-12, 2021. Amy Welty presented parts of the presentations "Iodine Capture Sorbent Development and Testing" and "Xe/Kr Sorbent Development and Testing." (N. Soelberg)

INL completed milestone M3FT-21IN030104013, reporting the results of initial research to determine Xe and Kr adsorption behavior on AgZ-PAN and HZ-PAN in argon. This study shows that AgZ-PAN has 2.5 times higher Xe capacity in Ar carrier gas than in air, while HZ-PAN Kr capacity in Ar is similar to air. While further research is needed to optimize temperature, flow, and pressure conditions, these results are encouraging given the current drive toward advanced reactors. (A. Welty)

2.4 Zircex

[INL] The MRPP completed the initial aluminum testing campaign and completed the associated milestone. Completion of this testing was successful and will allow the pilot plant to move to the next phase of testing. This next testing campaign will involve larger samples of Zr and Al that will be representative of the unirradiated fuel to be tested during the next FY. (M. Warner)

2.5 EBR-II Acceleration

[INL] Completed electrorefining of the 2nd FY21 EBR-II Driver Fuel Treatment Batch

Completed receipt of the 8th of 12 planned FY21 EBR-II driver fuel shipments from INTEC to FCF.

Completed moisture inspection on fuel bottles received in FY21 shipment #7

Completed 1 uranium dendrite distillation run and 1 cladding hull salt distillation run in the Cathode Processor

Completed the 3rd & 4th FY21 HALEU parent ingot production runs in the Casting Furnace in FCF. These ingots will be recast into regulus later in the year

Completed the Contractor Readiness Assessment for the new handling and out of cell storage method for HALEU reguli. (M. Patterson)

2.6 Innovative Process Control Capability

2.6.1 Pyrochemical Science and Technology

[INL] New work scope was added for May of FY21 to address some of the salt sampling statistical variations that have been observed for close-coupled oxide reduction and electrorefiner systems during the electrometallurgical treatment of spent oxide nuclear fuel. The new work scope includes the development of a filtered salt sampling system to remove particulate matter from salt samples, scatter replication experiments to determine the root cause of the statistical variation that has been observed, as well as investigations into actinide oxychloride thermodynamics and quantitative analysis methods. Additionally, the work scope associated with the U-TRU Co-deposition equipment development from the Pyro/Molten Salt Chemistry work package (FT-21IN03010202) has been incorporated into this work package.

For the previously existing work scope in this work package, the molten salt natural circulation flow loop electrical and pneumatic design was finalized, and the fabrication contract for the long-lead items was issued. (W. Phillips)

[PNNL] The team is finalizing setup of a corrosion vessel study and will begin heating vessels in the next month. These will provide an initial first look at representative corrosion products from different metal vessel materials. (A. Lines)

2.6.2 Aqueous Separation Science & Novel Processes

[ANL] The steady state AMUSE code was compiled into an executable (ssAMUSE.exe) that can be used with the MATLAB Runtime Environment. The AMUSE front end (Excel version) was updated to call ssAMUSE.exe. Currently the option exists to run either the Excel version or the MATLAB version of AMUSE by selecting the appropriate option button to allow developers to compare results between the two versions. Eventually, only the MATLAB version will be available to users. An FE Loop call was also added to the new AMUSE front end; FE Loop provides a way to run multiple flowsheets from existing flowsheet files rather than repeatedly inputting data through the AMUSE front end. The compiled executable was also interfaced with the Excel SP_DATA. SP_DATA allows users to obtain speciation information when developing equilibrium extraction models from experimental data. This new user interface includes new functionality that allows parameters to be specified that were previously inaccessible. Documentation included in the user interface was also expanded.

D-value data for extraction of uranium with DEHiBA (N,N-di-(2-ethylhexyl) isobutyramide) were received from PNNL. This data will enable creation of D-value models for an amide-based flowsheet for HALEU recycle. (C. Pereira)

[ORNL] The research progress and future plans were presented during the MRWFD Spring Meeting on May 12. The list of new neutral mono- and bidentate extractants for selective U/Pu separation and aqueous holdback agents for Tc was presented. The synthesis of cyclic urea based extractant has been completed, the substrate will be shipped to INL for further testing. (S. Jansone-Popova)

[PNNL] The extraction of uranium with *N,N*-di-(2-ethylhexyl)isobutyramide (DEHiBA) was investigated under conditions of high uranium loading. The distribution ratio data for extraction of uranium from nitric acid (HNO_3) solutions into a solvent consisting of 1.5 M DEHiBA dissolved in *n*-dodecane were provided to researchers at Argonne National Laboratory (ANL) for incorporation into the AMUSE flowsheet modeling program. Transfer of the data to ANL fulfilled milestone M3FT-21PN030402039, *Provide Uranium/DEHiBA Distribution Data to ANL*. The relevant uranium distribution data are presented in Figure 8. Increasing initial uranium concentration in the aqueous phase substantially suppresses the uranium distribution ratios due to loading of the solvent with uranium. Based on these data, conditions in which the aqueous phase uranium concentration in the extraction stages is 0.5 M or below, and 4 – 5 M HNO_3 are recommended. Researchers at ANL will develop a proposed flowsheet based on these results.

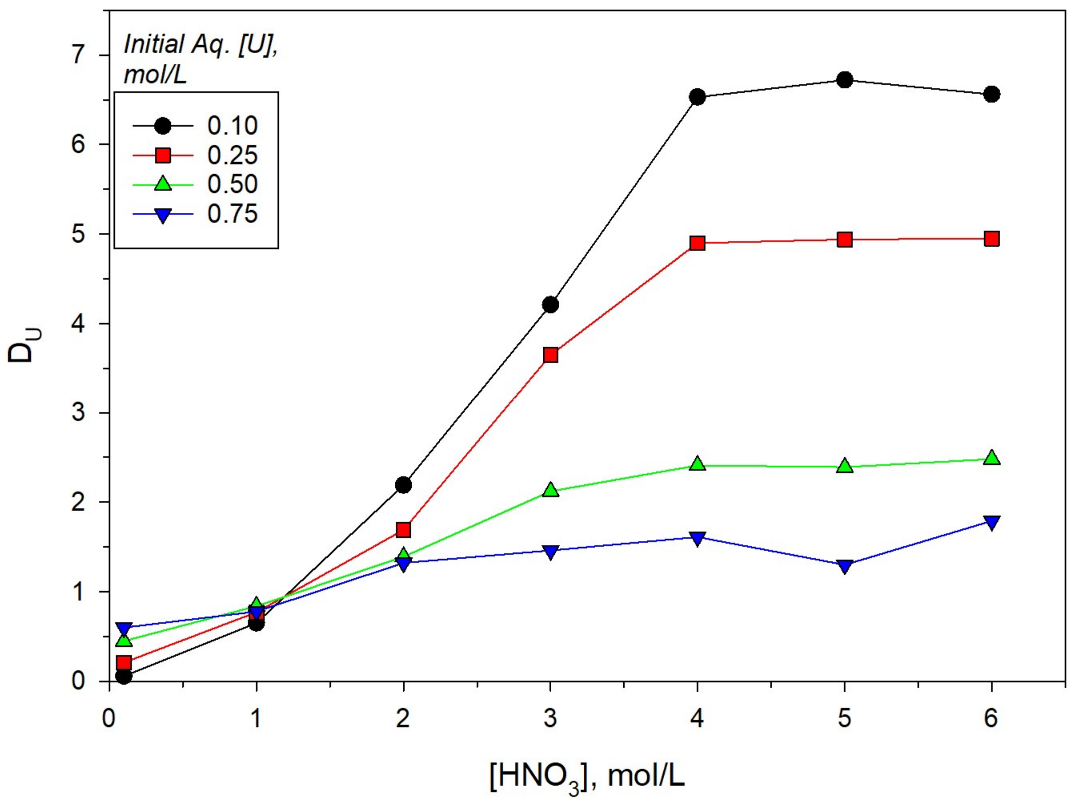

Figure 8. Uranium distribution ratios for extraction into 1.5 M DEHiBA/*n*-dodecane as a function of nitric acid concentration, and initial aqueous-phase uranium concentrations from 0.1 – 0.75 M.

The uranium distribution ratios for extraction into 1.5 M DEHiBA/*n*-dodecane were also measured as a function of temperature at 5 M HNO_3, starting with an initial uranium concentration of 0.5 M in the aqueous phase. Plotting the log(D_U) values versus the inverse of the temperature indicated a linear relationship with positive slope (**Error! Reference source not found.**) indicating the extraction reaction is exothermic. Based on these results, the enthalpy of uranium extraction under these conditions was calculated to be -13.9 kJ/mol. This value is comparable to others reported in the literature for the extraction of uranium by DEHiBA. (Emily Campbell and Gregg Lumetta)

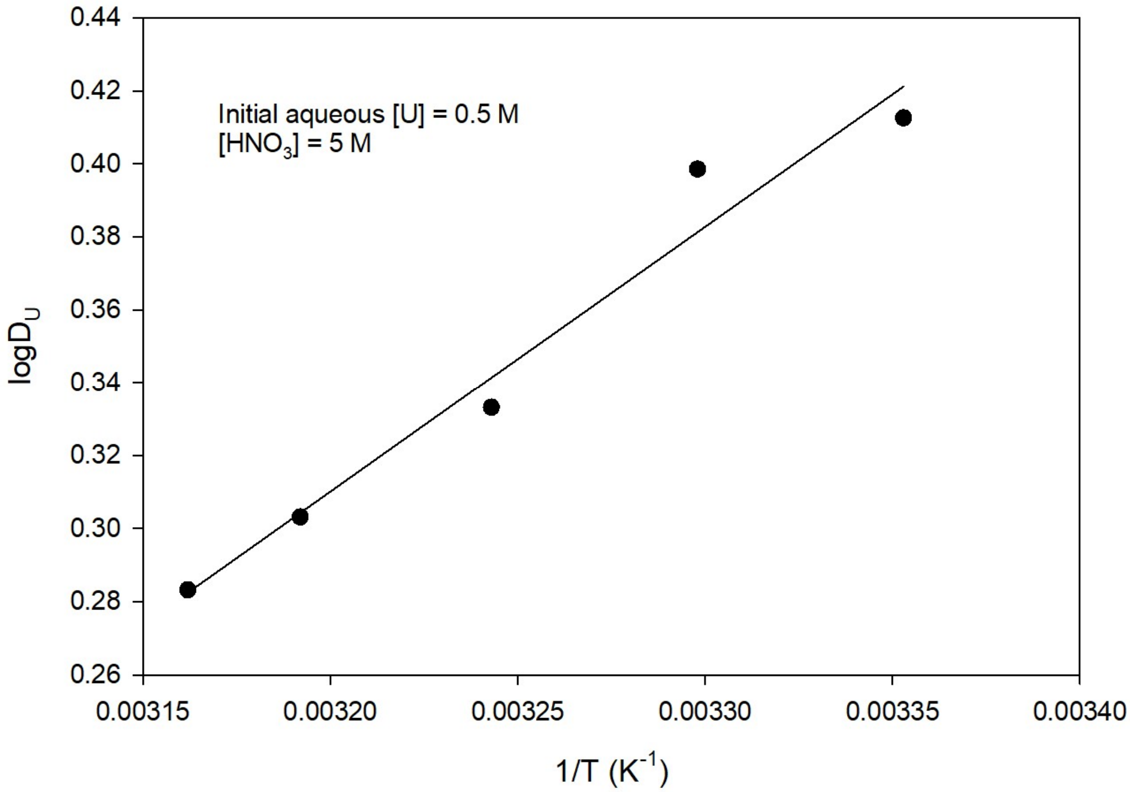

Figure 9 Temperature dependence of the uranium distribution ratio for extraction from 5 M HNO_3 into 1.5 M DEHiBA/*n*-dodecane; initial aqueous uranium concentration = 0.5 M, T = 25 – 43 °C).

2.7 Joint Fuel Cycle Studies

[INL] Completed the “Critical IRT demonstration test in HFEF” Level 2 milestone.

Critical Gap Highlights:

- Tests demonstrating drawdown of U/TRU from ER salt continued in May.
- Fabrication of new irradiation test pieces from recovered U/TRU material continued at the Fuel Manufacturing Facility in May. (J. King)

For more information on Material Recovery and Waste Forms Development contact Ken Marsden (208) 533-7864.

3. MPACT CAMPAIGN

3.1 Campaign Management

3.1.1 NTD & Management Support

[LANL] – MPACT CAM collected and distributed material from the annual MPACT spring meeting held April 26-28, 2021.

3.2 Immediate NMAC Needs

3.2.1 Bulk Handling Facility Holdup NMAC

[ORNL] Completed Westinghouse Fuel Fabrication visit on May 24, 2021.

3.2.2 SSBD Advanced Reactor Fuel Fabrication & Reprocessing

[LANL] (HALEU) MPACT has completed initial discussions with Centrus identifying potential areas of cooperation. Most of the Centrus-identified items are of interest to MPACT from a specific support perspective or a general NMAC interest perspective. The next step is to hold a series of VTCs to discuss each item individually in more detail with MPACT experts relevant to each topical area. These calls will be summarized as part of a cooperation assessment and will be factored into the MPACT FY22 planning package as appropriate.

3.2.3 SSBD Advanced Reactor Fuel Fabrication & Reprocessing

[SNL] The Zircex modeling work is being written up into a milestone report. A visit to the Westinghouse Fuel Fabrication facility in Columbia, SC was completed to help inform current work on holdup.

3.2.4 MPACT Support for DOE/NE-DOE/NNSA Discussion

[ANL] Follow-on ER voltammetry sensor demonstration activities will begin once the ER system is operational at INL.

[BNL] Reviewed MPACT response to Centrus. Drafted section on Increased Regulatory Certainty that identified ways that MPACT could assist Centrus with addressing gaps in the current NRC NMAC regulations.

3.2.5 ITV Support

[ANL] Plans are being developed for the proposed salt sampling technology demonstration and assessment.

3.2.6 ER Voltammetry Tests at INL

[ANL] Additional voltammetry testing has taken place in the HFEF electrorefiner. The recent testing involved planned temperature changes from 475C to 550C to assess the degree to which the sensor can appropriately respond to changes in salt density, species diffusion coefficients, etc.

3.2.7 INL & LANL PSMC Upgrades

[LANL] All the PSMC 3He rings are working well, and all amplifiers have been successfully gain matched. Noise issues from a switching power supply have been resolved. In June, multiplicity and dead time measurements will be performed as part of the initial performance benchmark of the upgraded system.

3.3 NMAC Tool Development

3.3.1 Electrochemical & Aqueous spike-based Reprocessing NMAC

[INL] Reviewed the existing gamma spectroscopy data for JFCS ER and Mark-IV ER salt samples. Analyzed possible sources to improve measurement uncertainties of samples taken from molten salt after 22Na tracer is added.

3.4 Facility Specific NMAC R&D

3.4.1 Domestic NMAC to Domestic NMAC Cooperation

[ANL/LANL/BNL] Discussions with a potential foreign collaborator placed on hold while USG reviewed policy on new foreign collaborations. Discussions with foreign entity will resume as soon as go ahead received from DOE-NE.

3.4.2 Microcalorimetry Installation

[LANL] Testing of the first microsnout assembly at University of Colorado and NIST has been completed. Transfer to LANL is expected in June. The second microsnout has been assembled and testing is in progress. All cryogenic components except for the detector assembly have now been received and installed in the system at LANL.

3.5 NMAC Fundamental R&D

3.5.1 Reprocessing Sampler

[ANL] Design work and safety planning continued for the installation of the salt sampler on the co-deposition electrorefiner.

For more information on MPACT contact Mike Browne at (505) 665-5056.

4. SYSTEMS ANALYSIS AND INTEGRATION (SA&I) CAMPAIGN

4.1 CAMPAIGN MANAGEMENT

[**ANL, BNL, INL, LLNL, ORNL, PNNL, SNL**] Discussed and prioritized the potential work scope for FY 2022 with engagements of the lab leads and inputs from campaign personnel.

4.2 NUCLEAR ENERGY SYSTEM PERFORMANCE (NESP)

4.2.1 Reactor Power Size Impacts on Nuclear Competitiveness in a Carbon-Constrained Future

[**ANL, BNL, ORNL, PNNL**] The ANL team has been working closely with other labs (BNL, ORNL, PNNL) to converge to a baseline capacity expansion scenario for deep decarbonization of the electricity grid that includes deployment of nuclear together with variable renewables, battery storage, and natural gas associated with carbon capture and sequestration. Sensitivity analyses were initiated at ANL to refine the A-LEAF model, and to assess the impact of different technology cost on the decarbonization scenario. Tentatively, it was found that the amount of nuclear deployment is heavily dependent on the long-term capital cost of the competing technologies and the prevailing price of carbon dioxide emissions, if any.

[PNNL] Revised and updated quick turnaround assessment of US mid-century deep-decarbonization goal and the projection of nuclear energy use for quantifying the scale of potential advanced nuclear fuel demands.

[PNNL] Attended working meeting and provided guidance on ongoing analysis of reactor size impacts on nuclear competitiveness.

4.2.2 Preliminary Technology Readiness Assessment and Scenario Analysis Studies of Fuel Cycle Facilities for Two Demonstration Reactor Designs

[**ANL**] Continued to work with DYMOND to replicate the HALEU projection exercise in April and to develop the base scenario to study the requirements for potential deployment profiles of Natrium reactors. Functionalities are being added to accurately model aspects of the Natrium and Natrium-Ultimate fuel cycles.

[INL] Developing an outline for the fuel cycle technology readiness report. The report is to cover readiness of fuel cycle facilities for deployment of the Natrium and Xe-100 concepts. Only a limited number of issues have been identified.

4.2.3 Maintain/Update of Fuel Cycle Catalog

[SNL] Continued to ensure that the public Nuclear Fuel Cycle Options Catalog is available on Sandia's Connect site, and to work toward moving the catalog to the cloud. We have also returned to finishing entering and verifying data for a fuel, a reactor, and two fuel cycle options. This work had been put on hold while we were focusing on moving the catalog to the cloud.

[SNL] We have been given a website on SNL's cloud and have been ensuring that it has the same information as the previous website (on SNL's Connect site) and that it looks as much like the previous website as possible. The database and the database reporting services associated with the catalog are not yet authorized to be used in the cloud. The authority to operate has been requested from the NNSA; we are waiting for their response.

4.2.4 Quick Turn-Around Studies

[**ANL**] Provided discharge fuel compositions of once-through and continuous recycling fuel cycles with PWR, HTGR, and SFR to Dr. M. Regalbuto of INL. The data were obtained from the Fuel Cycle Data Package (FCDP) developed under the fuel cycle evaluation and screening study.

[INL] Initiated an update of the HALEU analysis performed in April for NE-4.

4.2.5 Support DOE NE in international engagements

[ANL] Participated in TWOFCS (Technical Workshop on Nuclear Fuel Cycle Simulation) international fuel cycle workshop scientific committee meeting on organizing sessions based on 26 submitted abstracts.

[INL] Chaired a remote meeting of the Nuclear Energy Agency Expert Group on Advanced Fuel Cycle Scenarios on May 6th. The meeting focused on the current TRU management study phase 2 main results presentation approach.

[INL] Participated in an invited review of the International Energy Agency's draft "Electricity Market Report - 2021"

4.3 ECONOMIC AND MARKET ANALYSIS FOR NUCLEAR ENERGY SYSTEMS (EMANES)

4.3.1 Nuclear Utilization Impacts on Transportation Sector Electrification

[INL] Participated in a presentation of the developing ANL market analysis toolset and provided feedback on development direction.

4.3.2 Cost Drivers for Fuel Recycling Facilities

[**ANL**] The list of cost driver areas of the fuel fabrication facility was developed for further exploration. There are eight cost driver areas that need to be better understood to develop potential ways to reduce. All areas will be explored in more detail and ways to try and reduce if practical will be identified. The areas include fabrication levels (glovebox, shielded glovebox, …), limits that result in moving up a level at significant cost, storage costs of completed fuel assemblies, hardware (cladding, ducts, etc.) cost, material costs, et al. Specific references and expert feedback are being pursued to better understand these cost drivers for the fuel fabrication facility’s contribution to the cost (upfront capital and levelized) of recycle facilities.

4.3.3 Deploy Next-Generation Capacity Expansion and Dispatch Models for Electricity Market Analysis

[**ANL**] The development of the Agent Based Capacity Expansion code (ABCE) is moving forward. Agents' ability to anticipate and respond to future events was expanded, with newly implemented ability to consider future project opportunities and perform more sophisticated demand forecasting. The current capabilities were presented to the extended team involved in this project within the campaign to gather feedback.

4.3.4 Expand Cost Algorithm and Techno-economic Assessment Tools

[**ANL**] The algorithms of previous ACCERT reports (the original report in FY 2017 and the update in FY2018, the revision and other applications in FY2019) were incorporated into the draft Rev 0 of the consolidated ACCERT report. The basic approach for developing the ACCERT software has been developed. Integration of the ACCERT report and the software seems to be critical for both. This may require updates to the draft report either in Rev 1 or delaying the release of Rev 0 depending on the timeline. The software seems feasible at this point, but the issue seems to more revolve around cost/time to develop and the value of the software. These areas are being addressed. The draft deliverable report was nearly complete. Some additional inputs are required from ANL and INL. Work is ongoing according to plan.

[INL] A full draft of a non-milestone report on economics-by-design using the microreactor code of accounts was completed and reviewed. The draft was also presented to the microreactors NTD with positive feedback. Comment resolution is in progress.

4.3.5 Cost Basis Report Improvement/Update

[INL] A major update of the Cost Basis Report website has been developed and is in testing/review. Drafting of the milestone report is underway.

For more information on Systems Analysis and Integration contact Temitope Taiwo (630) 252-1387.

5. JOINT FUEL CYCLE STUDY ACTIVITIES

INL and KAERI fuels experts held a meeting discussing recent fabrication progress and plans for upcoming experiments.

IRT Highlights:

- The sixth 4 kg-scale electrorefining test with reduced irradiated LWR fuel was completed in April. This marked the completion of primary IRT experiments.

Critical Gap Highlights:

- Tests demonstrating drawdown of U/TRU from ER salt continued in May.
- Fabrication of new irradiation test pieces from recovered U/TRU material continued at the Fuel Manufacturing Facility in May.
- The waste form team held a discussion between INL, ANL, PNNL and KAERI to share recent experimental results and plan upcoming experiments

For more information on Joint Fuel Cycle Studies Activities contact Ken Marsden (208) 533-7864.

6. AFCI-HQ PROGRAM SUPPORT

Site: University Research Alliance at West Texas A&M University in Canyon, Texas and the following universities: Ohio State University, University of Tennessee at Knoxville, Georgia Institute of Technology, University of Idaho, Colorado School of Mines, University of South Carolina, Florida State University, Northwestern University, Clemson University, North Carolina State University, University of Utah**,** University of Chicago, Columbia University, University of Toledo, and other universities.

Universities engaged in Nuclear Technology research via URA programs since 2001:

- Boise State University
- Boston College
- Clemson University
- Colorado School of Mines
- Columbia University
- Georgia Institute of Technology
- Georgetown University
- Idaho State University
- Florida International University
- Florida State University
- Kansas State University
- Massachusetts Institute of Technology
- Missouri University of Science and Technology
- North Carolina State University
- Northern Illinois University
- Northwestern University
- Ohio State University
- Oregon State University
- Pennsylvania State University
- Purdue University
- Rensselaer Polytechnic Institute
- Rutgers University
- Texas A&M University
- University of Arkansas
- University of California at Berkeley
- University of California at Santa Barbara
- University of California at Davis
- University of Chicago
- University of Cincinnati
- University of Florida
- University of Idaho
- University of Illinois at Urbana-Champaign
- University of Michigan
- University of Missouri
- University of Nevada at Las Vegas
- University of New Mexico
- University of North Texas
- University of Notre Dame
- University of Ohio
- University of South Carolina
- University of Tennessee at Knoxville
- University of Texas at Austin
- University of Toledo
- University of Utah
- University of Virginia
- University of Wisconsin
- Vanderbilt University
- Virginia Commonwealth University
- Washington State University

6.1 Innovations in Nuclear Technology R&D Awards

6.1.1 University Programs

6.1.1.1 Summary Report

University Research Alliance announced the 2021 Innovations Awards at the end of January. The announcement was made via opening the website to accept applications and announcing the program to university students and faculty in relevant disciplines. The announcement was sent several times in an effort to reach every eligible student and to remind faculty and students of the application deadline.

The original deadline for 2021 was midnight, Sunday March 14. Due to the continuing situation associated with COVID-19, the deadline was extended to Sunday March 21.

University Research Alliance compiled and distributed the 2021 application packages to three reviewers for scoring and comments on April 2. One reviewer dropped out for personal reasons, and three other reviewers were asked to evaluate the applications. The reviews were conducted by Dr. Catherine Riddle of Idaho National Laboratory, Dr. James Willit of Argonne National Laboratory, Dr. Gabriel Hall of Pacific Northwest National Laboratory, Dr. James King of Idaho National Laboratory, and Mr. Kenneth Kellar of the DOE.

The reviewers' scores were received by May 17. Results were compiled, and recommendations for winners were sent to DOE for approval on May 19. Dr. Stephen Kung, Acting Director of the Office of Materials and Chemical Technologies, reviewed the applications on behalf of the DOE. Dr. Kung approved the reviewers' selections on May 21. All of the winners, and those who did not win, were notified by May 26.

Twenty-two students were selected as award winners. The 2021 Innovations in Nuclear Technology R&D Awards winners are:

Advanced Fuels

- Walter Williams, Purdue University
- Steven Jepeal, Massachusetts Institute of Technology

Advanced Reactors

- Naiki Kaffezakis, Georgia Institute of Technology
- Bodhisatwa Biswas, Massachusetts Institute of Technology

Material Protection, Control, and Accountancy

- Matthew Durbin, Pennsylvania State University
- Jacob Blevins, North Carolina State University

Material Recovery and Waste Form Development

- Devon Drey, University of Tennessee at Knoxville
- Hope Lackey, Washington State University

Nuclear Science and Engineering

- Gabriela Picayo, Colorado School of Mines
- Osvaldo Ordoñez, University of California at Santa Barbara

Used Fuel Disposition

- Logan Breton, University of South Carolina
- Jordan Stanberry, University of Central Florida

Competition for Students at Universities with Less than $600 Million in 2019 Science and Engineering R&D Expenditures

- Edward Duchnowski, University of Tennessee at Knoxville
- James Foster, Clemson University
- Robert Kile, University of Tennessee at Knoxville
- Dmitris Killinger, Virginia Commonwealth University
- Ashwin Rao, Air Force Institute of Technology

Undergraduate Competition

- Kaitlyn Barr, University of Michigan
- Mete Bayrak, University of Texas at Austin
- Victoria Davis, Virginia Commonwealth University
- Ashley Raster, Missouri Institute of Science and Technology
- Matthew Weiss, University of Illinois at Urbana-Champaign

University Research Alliance began collecting information to process the award checks for the 2021 Innovations Awards winners.

University Research Alliance prepared letters of congratulations for the award winners, to be signed by a DOE official, which will be included with the award trophies.

University Research Alliance began preparing press releases on behalf of the 2021 Innovations Awards winners. Winners' university department heads, advisors, and newspapers are among those who will be formally notified of their achievement.

University Research Alliance began collecting information to post the 2021 Innovations Awards announcement on the nucleartechinnovations.org website.

University Research Alliance assisted First Place winners in submitting summaries for the Innovations Awards special session at the ANS Winter Meeting in November. All of the summaries are on track to be submitted by the ANS deadline of July 13.

University Research Alliance continued to update the Innovations Awards announcement distribution list and remove people who have asked to be removed from the list.

For more information on the University Research Alliance contact Cathy Dixon (806) 651-3401.