INL/RPT-24-76252

Nuclear Fuel Cycle and Supply Chain (NFCSC) Technical Monthly November FY-24

Changing the World's Energy Future

November 2023

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

DISCLAIMER

This information was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness, of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

INL/RPT-24-76252

Nuclear Fuel Cycle and Supply Chain (NFCSC) Technical Monthly November FY-24

November 2023

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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

CONTENTS

FIGURES

Nuclear Fuel Cycle and Supply Chain (NFCSC) Technical Monthly November FY-24

1. ADVANCED FUELS CAMPAIGN (AFC)

1.1 Campaign Management and Integration

The AFC FY23 Annual Meeting was held at Texas W&M University (College Station, TX) November 7-9, 2023. Participants from DOE-HQ, DOE-ID, National Laboratories, Industry, and Universities reported on FY23 accomplishments from the Campaign. Tours of TAMU laboratories (Fuel Cycle & Materials Laboratory, Accelerator Laboratory, and Thermal-Hydraulic Research Laboratory) were also given.

1.2 International Collaborations

Alex Swearingen attended the Materials Modelling and Simulation for Nuclear Fuel Workshop (MMSNF 2023) in Ontario, Canada. Work was presented on the comparison of Fission Accelerated Steady-state Test (FAST) experiments with BISON computational simulations. Collaboration with other attendees of the modelling community on methods and best practices for modelling of nuclear fuels also occurred. The end goal was to foster an international network of researchers with a wide range of experience in the fields of fuel performance modeling and metallic fuel design. Developing this network will allow for outside perspectives to offer novel insight on the modeling of FAST experiments and how to best utilize the simulation results to inform design decisions for AFC and aLEU applications.

Cindy Adkins participated in the Thermodynamics of Advanced Fuels - International Database (TAF-ID) Programme Review Group in Hamilton, Canada. This meeting provided access to the international community's efforts in thermodynamic database development along with state-of-the-art characterization of advanced nuclear fuels and materials. This information will be incorporated into the work performed at Idaho National Laboratory. New techniques and approaches provide the ability to perform new and more accurate examinations for DOE programs. Presentations of recent work at Idaho National Laboratory were given. Discussions were held with other countries including recent testing results and collaboration efforts of fuel development, characterization advances, and thermodynamic modeling techniques.

International discussion on quantifying microstructure of advanced nuclear fuel forms, the measurement of post-irradiated thermodynamic properties and the interpretation of results were also held. Published data will be added to the TAF-ID working database.

AFC Staff (Nicolas Woolstenhulme, Klint Anderson, and Nate Oldham) attended the DEVICE-MTR Working Group Meeting in Mito, Japan. The DEVICE-MTR working group is a collection of experienced irradiation test designers and engineers from the premier materials test reactors around the world. Attendees of this meeting presented current efforts and design solutions as they collaborated on common issues in this niche field of research. Participation in this meeting will help ensure that DOE's fuels and materials test programs are using state-of-the-art irradiation strategies to help accelerate the development of advanced fuels and materials. Participants in the meeting networked and collaborated with other attendees to help solidify plans for developing irradiation capabilities and future research proposals under cooperative frameworks such as FIDES.

Aaron Colldeweih traveled to Villigen, Switzerland to perform neutron radiography measurements using one of the world's highest resolution neutron radiography facilities to examine the performance of ATF cladding under loss of coolant accident (LOCA) conditions simulated at INL and ORNL. The measurements will provide never-before post-LOCA test information on the pre-strained ATF cladding in support of the ATF cladding development. This travel also provides an opportunity to gain technical information that will help develop high-resolution radiography capabilities at the NRAD reactor at INL. INL is the world leader in nuclear fuel and materials research and development. During this travel, experiments using neutron radiography at the world-renowned Neutron Microscope (NM) at the Paul Scherrer Institute (PSI) were employed for advanced characterization of Accident Tolerant Fuels (ATF) cladding. The chromium coated cladding analyzed in this work is a leading concept of ATF cladding being developed in the US within the Advanced Fuels Campaign (AFC) program.

1.3 Industry FOA

1.3.1 WESTINGHOUSE ATF FOA

[INL] Completed Inversion and Sectioning Fixture for Byron, enabling full-length pin inversion for Destructive Examination. Continued preparation for Byron Shipment

1.4 ATF Lab Activities

1.4.1 ATF SAFETY TESTING

[INL] Design work required to transition to the new experiment containment vehicle continued. The third and fourth capsules completed final assembly and are ready for irradiation.

1.4.2 ATF POST IRRADIATION EXAMINATION

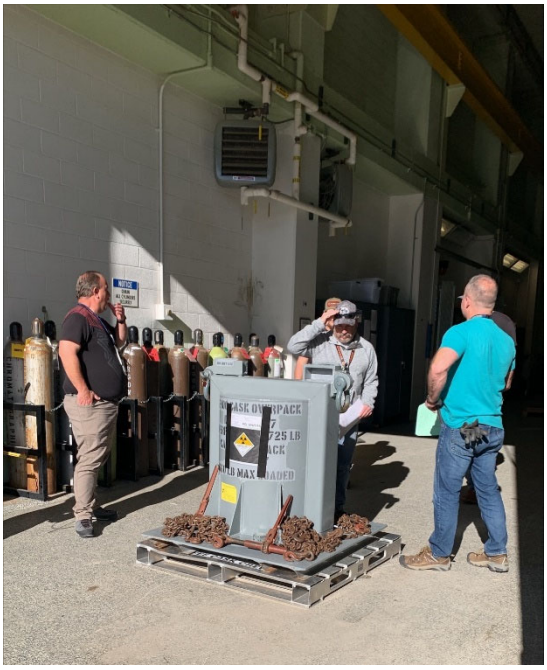
[INL] Efforts continued with the integrated team preparing to load and ship the 25 ATF/JFCS Fuel Rods stored at Byron Generating Station (BGS) to INL for ATF R&D efforts to support RIA/LOCA tests planned for the coming years.

[INL] Final design of the equipment has been approved and released to manufacturing, with an expected ship date from Germany on 2/20/24.

1.5 Advanced Reactor Fuels

1.5.1 AR Irradiation Testing

[INL] FAST-1 ATR cycle 171B-1 as-run and 173A/B-1 cycle projections analyses are in process. The FAST-1 shipment to HFEF was completed on 11/16/23 (M3FT-24IN020303015). Irradiation support hardware fabrication is now complete. Flux-wire monitors are delivered to ATR, and cadmium baskets are nearing quality inspection completion and will be transferred to ATR next month.



Following the FIDES-II meeting in Mito, Japan and presentation of the AToMiC experiment proposal, follow-up presentation sessions were held to finalize the proposal. The project will now move toward the review/approval phase, planned for the next few reporting periods.

BEAST bi-weekly meetings have resumed to investigate test bed configurations and address open design questions. With the South Flux Trap now reserved for Naval Research experiments, BEAST was modified for the Northeast Flux Trap (NEFT). Neutronics analysis was performed to compare powers of test configurations utilizing Booster fuel vs. fuel pins. Sensitivity analysis was executed to explore the effects of replacing NEFT coolant with material densities of Extended Life Aluminide Fuel (ELAF).

1.5.2 AR Safety Testing

[INL] The THOR phase III hot cell installation of disassembly equipment is progressing. See images below.

Figure 1. Disassembly and furnace image.

[INL] The project team found a way to minimize the helium escape routes at the Conax wire joints for THOR. This is significant because of the time and money spent troubleshooting during the assembly of past THOR's. See image below.

Figure 2. Conax leak rate testing.

[INL] The THOR project is advancing steadily with the redesign and fabrication of the heat sink. The team is preparing to send new requests for the fabrication of the improved heat sink design soon.

[INL] RFP documentation, including specifications and drawings, are being finalized for the NFPA 1-hour rated fire enclosure.

[INL] Functional & Operational Requirements document FOR-967 for the Modular Sodium Test Loop that will be located in IEDF, was submitted for DCR review.

1.6 Silicon-Carbide Cladding

1.6.1 SiC Cladding Lab Activities

[ORNL] Significant progress has been made for the milestone M2FT-24OR020501013: SiC modeling Supporting Tube bowing evaluations. During this reporting period, dimensional and profile scanning of the irradiated SiC composite tubes fabricated by General Atomics was conducted using the custom profilometry rig. Analysis of the tube dimensions before and after irradiation quantified irradiation-induced bowing of the SiC tube specimens in an intentional neutron flux gradient in HFIR (Fig. 1). The bowing data will be used to validate or improve the current deformation model to predict the in-pile performance of SiC/SiC composite cladding for light-water reactor applications.

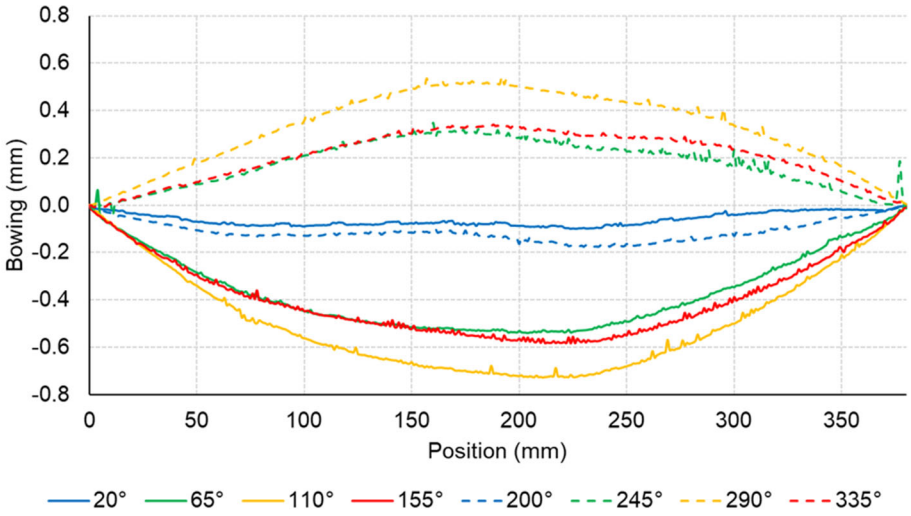


Figure 3. Bowing of the irradiated SiC composite tubes specimen surface with different rotation angles.

[INL] A manuscript titled "Multi-scale Characterization of Porosity and Cracks in Silicon Carbide Cladding after Transient Reactor Test Facility Irradiation" was published in Energies (IF=3.3). This paper presented the first set of advanced characterization data for TREAT irradiated SiC cladding, which revealed leak mechanisms using computed tomography and in-house developed data analytic methods.

[INL] Continued discussions with the Czech Republic on a possible collaboration with a SiC experiment at TREAT.

1.6.2 GA SiC Cladding (FOA)

[INL] Design of irradiation capsule for SiC fiber specimens was finalized. Procurement of the capsule components was initiated.

1.7 Capability Development

1.7.1 ATR Loop Installation

[INL] The Transfer Shield Plate and Shield Cylinder fabrication long lead procurement subcontract was awarded on November 10, 2023, at a favorable price with a completion date of November 11, 2024. With

the exception of the lead pour, the subcontractor will self-perform the fabrication at their tri-city Washington facilities.

- The Transfer Shield Plate and Shield Cylinder fabrication subcontract kick off meeting was held on November 22, 2023, and the subcontractor will update its fabrication schedule within 2 weeks which will be included in the project life cycle, PICs, and Earned Value baseline plans through the Budget Change Process.
- The strategy to establish a US domestic I Loop Tube supply capability was completed and routed for approval.
- Continued the 1A primary and secondary cubicle out of service equipment removal and rip out to be completed during the 172A outage.
- Competed preliminary cubicle wall design modifications.

1.7.2 REFABRICATION AND INSTRUMENTATION CAPABILITY

[INL] Continuing to work on welding parameters and new tooling in support of the Byron fuel rodlet refabrication planned for later this year (see results in photo).

[INL] Initiated and received approval on engineering changes for welding system modifications, dissolution station, and rodlet press modifications. These activities will also support the Byron fuel rodlet refabrication planned for later this year.

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

2. MATERIAL RECOVERY & WASTE FORM DEVELOPMENT CAMPAIGN

2.1 Waste Forms & Off-Gas Capture

[ANL] Discussions were held with collaborators at PNNL to develop test plans for coordinated testing of iodide waste forms to parameterize the degradation model and enhanced formulation of the iron phosphate waste form to improve cesium retention. Archived IWF materials available for use in tests were identified and a test plan was drafted for activities with both material types at both labs. A workshop was held on October 17-19, 2023, at Argonne to discuss the status of cermet material production and durability to support possible use of cermets as waste forms for high-level radioactive wastes. A report summarizing insights based on the workshop and recommendations is being drafted.

2.2 Vapor Phase Processes

[INL] In November, the INL vapor phase project team matured concepts for an advanced voloxidation design for utilizing NO2 for the voloxidation of used nuclear fuel in the HFEF hot cell. A first draft concept drawing was developed that uses the existing DEOX furnace in the HFEF hot cell with new supplemental hardware. The team also met with HFEF facility management to obtain concurrence on the general approach for deploying the hazardous gas in the hot cell. Additionally, a preliminary list of inputs/requirements for a direct extraction technique for in the hot cell was developed by the project team. Iterations on this list and development of an associated design concept are ongoing.

[PNNL] The safety documentation and installation of equipment for the ozone voloxidation of UO2 and U3O8 to ϵ-UO3 was completed during the month of November. Testing the voloxidation setup has been initiated. Initial testing consists of taking timed samples from bulk voloxidation samples and analyzing by powder X-ray diffraction and oxidation state determination by dissolution in phosphoric acid. This step is necessary to understand the duration of voloxidation that is necessary to achieve pure ϵ-UO3.

Methodology for determining the concentration of HNO2 in both organic and aqueous solutions has been initiated. The ability to accurately determine the concentration of HNO2 in solution in a rapid manner will be vital to determining the reaction stoichiometry of direct dissolution in process solvents.

[SRNL] A series of solid solutions was prepared containing depleted uranium and one or more lanthanide elements by precipitation of the actinide/lanthanide mixtures using ammonium hydroxide and calcination to oxides (Figure 1). Direct extraction experiments were performed in which the rate of extraction was measured using visible spectroscopy. Performing the direct extraction experiments completes milestone M3FT-24SR030402163, complete kinetic measurements for lanthanide oxide dissolution in a TBP solvent. The extraction rates of the uranium-lanthanide oxides do not seem to be impacted by the particle size (i.e., clumped versus fine powder). Even though the visible spectroscopy confirms that most of the oxides are “dissolved” within a couple of hours, the dissolution of the uranium-lanthanide oxides has been incomplete even when left overnight in solution. Samples of the oxides will be analyzed by x-ray diffraction (once the SRNL instrument is back in service) to determine their structure.

Figure 4. Uranium – Lanthanide Solid Solutions (1) U-Nd, (2) U-Er, (3) U-Sm, (4) U-Nd-Er (5) U-Nd-Er-Sm, (6) U-Ce, (7) U-Nd-Er-Sm-Ce, and (8) U control

[ANL] An updated version of AMUSE v5 was compiled for internal testing after several changes were made. This version incorporates D value models for extraction of HNO3, U(VI), Pu(III), Pu(IV), Np(IV), Np(V), Np(VI) with DEHiBA and a preliminary approach to solvent loading effects for DEHiBA. An initial review of Tc and Zr extraction data for development of D value models for these components was performed.

The microfluidic systems developed in FY23 were modified with addition of an electrochemical redox electrode system to induce controlled oxidation-reduction reactions in process.

2.3 Pyro/Molten Salt Processing

[ANL] The assessment of alternative methods to remove salt from deposited metal products initiated in FY23 was completed and the report is being finalized. The salt separation report will be issued on schedule in November. Insights from that review are being used to plan construction of a testbed facility. Engineering enhancements for pyrochemical facilities used for deposition and drawdown are being identified. A test plan for removing active metal fission products from salt is being developed based on a review of alternative methods conducted during FY23.

[INL] Small group meetings continue to update progress on Nuclear Technology Transfer sheets strategy and CRADA approvals. Second-generation Mechanical Cutting and Decladding System (MCADS) equipment qualification continued in November and is expected to be completed in early CY24.

2.4 Innovative Aqueous

[ORNL] We continue to wait for the full integration of the system by the automation company. JKem has currently acquired all the required instruments including the robot arm, vials, centrifuge, and the design of the full instrument setup. We initially had a quick design that included the balance and centrifuge but not all instruments just to give a quick size estimation. The automated pipette instrument has been delivered on site and we are in the process of scheduling the installation.

[ANL] We have started to identify options for generalizing the AMUSE loading module following from a previous effort started under HZP. A set of minor code enhancements were completed to make corrections and facilitate handling of flowsheets with loaded organic feeds. It is being used to understand system behavior at higher loadings and develop a more accurate prediction of D value suppression when loading is high.

[LANL] We have now successfully completed four total cycles of the Bayesian Optimization (BO) experiments examining the extraction of Th(IV) with the DEHBA ligand. Each cycle consists of a series machine-learning (ML) generated conditions and with their predicted Th(IV) distribution ratios, then subsequent experiments are performed under those conditions. The experimental space being sampled includes various Th(IV) concentrations (0.1-5.0 mM), nitric acid concentrations (0.1-5.0 M), DEHBA concentrations (5-50 mM), and temperatures (25-75°C), covering 432 possible experiments. In this latest cycle (4), the BO model's prediction of Th(IV) D values has become very accurate compared to the earlier rounds.

High-throughput DFT calculations have been started to analyze the binding of U(VI) and *M*(IV) (*M*=Th/Pu) with the DEHBA and DEHiBA ligands at the molecular level. To explore variations in separation conditions, multiple different solvation environments were modeled using implicit solvation effects. By exploring the coordination environment of these different species with various H_2O, NO_3^- and extractant (DEHiBA or DEHBA), we have conducted over 500 DFT calculations. From these calculations, the lowest energy structures were used to investigate the reaction energies involving the stepwise coordination of the extractant ligands.

[PNNL] Innovative Aqueous - PNNL, FT-24PN03040212 Samples of uranium oxalate with Np and Pu comatrices have been prepared in anticipation of voloxidation under ozone gas in the coming months.

Two presentations given at the 21st Symposium on Separation Science and Technology for Energy Applications in Knoxville TN were focused on research performed under this program. Gabriel Hall gave an oral presentation on the direct dissolution of uranium oxides and simfuel into 1.5 M DEHiBA which was pre-contacted with nitric acid and Juan Cervantes gave a poster presentation on the dissolution of uranium in alkaline conditions.

2.5 Innovative Salt Systems

[ANL] Developmental chlorination tests using a Zr-mediated anode were completed and shake-down tests with the chlorine gas cathode were completed and are being documented. The chlorination report will be issued on schedule in November. The test plan for FY24 activities is being developed. Test plans for characterizing oxide particles in salt and demonstrating an oxide particle sensor are being developed.

[INL] A report has been generated to satisfy milestone M4FT-24IN030401027 (Define detailed salt crystallization activities for FY24). This report covers the detailed activities that will be performed as part of the salt crystallization development scope for FY24. This includes demonstrating salt crystallization and fission product concentration using fluoride salt systems relevant to molten salt reactors to satisfy M2FT-24IN030401021 (Potential of the crystallization technique for separation of challenging fission products in fluoride salt systems) and developing concepts for enhanced scalability and process efficiency to satisfy M4FT-24IN030401028 (Evaluation of Alternative Salt Crystallization Routes).

A report has also been generated to satisfy milestone M4FT-24IN0304010210 (Document recommended approaches for conversion of UFx compounds to UCl3). This report covers the motivation for and chemical reaction pathways that allow direct conversion of uranium fluoride compounds to uranium chloride compounds. This report also documents the planned experimental efforts for FY24 that will demonstrate these reaction pathways to determine the viability of future research and development efforts to satisfy M3FT-24IN0304010211 (Perform scoping experiments to demonstrate conversion of uranium fluorides to uranium chlorides).

The hardware necessary for deployment of the HCl sparging system into a radiological facility has been completed and validation testing of this apparatus in a non-radiological facility is planned for January 2024. Engineering documentation is complete for this system, and the final documents necessary for work control in the radiological facility are being completed. It is anticipated that the system will be available to deploy in a radiological facility prior to the milestone due date for M4FT-24IN0304010212 (Deploy in-situ salt halogenation system in radiological facility).

A team at INL has been established to work on this report, and initial discussions with relevant staff at ANL have been held to determine the path forward for generating the report that will satisfy M4FT-24IN0304010214 (Recommend Research Needs for Iodine Mass Tracking).

A team at INL has also been established to generate the report necessary to satisfy M4FT-24IN0304010215 (Develop a whitepaper on improved analytical methods for chloride, metal, oxide, and oxychloride speciation). This team is currently conducting literature reviews, including reviewing previous internal reports generated by the MRWFD campaign on similar topics.

[ORNL] We are measuring the solubility of $La_2O_3/Nd_2O_3/Ho_2O_3$, $Nd_2O_3/Ho_2O_3/Sm_2O_3$, Nd_2O_3/La_2O_3, Nd_2O_3/Ho_2O_3, and Nd_2O_3/Sm_2O_3 oxide mixtures in a $MgCl_2$-$CaCl_2$ eutectic melt in the temperature range of 650 – 800 °C. Preliminary data shows similar to the individual oxides trend of increasing RE oxides solubility from Ho to La. We have also been testing a MnO_2 based reference electrode at 500 °C in MgCl2-NaCl-KCl. A pair of well-defined redox peaks located around -0.05V vs Ag/AgCl is observed in the cyclic voltammogram. XRD analysis determined that the redox peaks are due to Mg ions reversibly intercalating and de-intercalating in the MnO_2. A Mg intercalated MnO_2 electrode was continuously tested for about 40 hours and demonstrated stable performance with a shift of about 20 mV.

A Neural Network Interatomic Potential (NNIP) is developed for $AlCl_3$ molten salt system. DeePMD was used to fit the NNIP using forces and energies from ab-initio molecular dynamics configurations collected from equilibrium volume including a variation of up to 20% expanded and compressed volumes at 498 K. The developed NNIP potential is used to evaluate the structure and thermophysical properties of $AlCl_3$ salt for temperatures ranging from 473-613 K. NNIP predicted viscosity values are within 7% of the reported experimental data. Nearly 8 nanosecond long two-phase simulations are performed to simulate the equilibrium liquid and vapor phase of $AlCl_3$, which helped predict phase diagram of $AlCl_3$ from NNIP-based molecular dynamics simulations. The predicted liquid and vapor densities using NNIP are validated using experimental data.

[BNL] Improving sample temperature conditioning and handling as planned in the previous milestone report and work package discussion meeting. Monodisperse Au and Pt nanoparticles have been ordered.

[PNNL] Processing of TRISO Fuels, FT-24PN03040106 (M Nutt) This project is aimed at establishing a process concept (block flow diagram and narrative) for preparing and dissolving TRISO spent carbide/nitride nuclear fuel for actinide recovery by solvent extraction. In November, we continued to accumulate and review literature on the topic of reprocessing spent carbide nuclear fuel and produced a report outline. We will develop the process concept and progress the report in December.

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 PROGRAM MANAGEMENT

[LANL] Federal Program Manager, Control Account Manager, Deputy National Technical Director, and National Technical Director continue to work with the MPACT website developer to finalize the initial website information. CAM has scheduled MPACT management calls with Lab POCs and Work Package Managers. These meetings will take place in December. Federal Program Manager and Deputy NTD have participated in various program reviews for MPACT coordination.

[BNL] Assisted the Federal Program Manager and the National Technical Director with designing the new MPACT website that will be used to conduct outreach to industry and other programs supporting advanced reactors. Working with the National Technical Director, began developing an MPACT outreach strategy to identify programs with which MPACT might coordinate and others with which MPACT might collaborate. Reviewed the "Safeguards Practitioner's Guidance Document" developed by SNL and provided comments to the NTD.

3.1.2 MPACT WEBSITE DEVELOPMENT

[LANL] The MPACT website development team continues to work with MPACT management to finalize the initial website information.

3.2 Front-End Domestic Safeguards

3.2.1 ENRICHMENT PLANT

[INL] Meeting with Centrus in coordination with other activities. Discussed plans going forward and options for future testing.

[SNL] ANS presentation given at ANS winter meeting provided an overview of SNL's enrichment modeling capability, including highlighting the application/opportunities for an enrichment model in analyzing facility-level or state-level material accounting strategies.

3.2.2 FUEL FABRICATION - HOLDUP

[ORNL] Completed in field testing. Report currently being reviewed for public release.

3.2.3 FUEL FABRICATION - STANDARDS

[ORNL] Continue to support Westinghouse while they work on the reference material fabrication.

3.3 Back-End Domestic Safeguards

3.3.1 MICROCALORIMETRY

[LANL] Continued support of microcalorimeter operations at INL. The current focus is understanding an intermittent noise issue that may be associated with facility operations or room temperature. Additional logging of diagnostic parameters has been set up. A trip to INL is planned for early CY24 to install the remaining detector assemblies and troubleshoot any issues.

[INL] Working with LANL, NIST, and UC Boulder to understand measurements. As part of this, UC Boulder sent a room temperature data logger to INL, LANL sent the code to log temperatures and pressures of the different cryostat stages. Had several meetings to discuss findings and options to improve performance.

[PNNL] The full energy peak of the microcalorimeter was measured from several spectra acquired in September of 2022. The ratio in the measured efficiency appears to be consistent between 50 and 230 keV and inconsistent at the lowest and highest energies. This may provide some insight into improving the consistency in the pixel summing.

3.3.2 SAFEGUARDS MODELING SUPPORT

[SNL] Implemented an experimental pipeline in MAPIT to support multiprocessing (a key goal for FY24). Consequently, updated the command line API to support multiprocessing. Started the process to host MAPIT on conda-forge for easier installation process.

3.3.3 MOLTEN SALT SAMPLING & SAMPLER

[ANL] Meetings between ANL and INL continued this month. The standard operating procedure for the sampler was sent to INL and reviewed during the meetings. INL and ANL began to fill out the template for the Functional and Operational Requirements (F&OR) for the installation of the sampler in the HFEF. To prepare for the F&OR and eventual Engineering Change, ANL has shared with INL all documentation on the sampler, including drawings, material testing reports, leak test reports, bill of material, and standard operating procedures.

[INL] Had several meetings with ANL and engineers at MFC/HFEF on the sampler. Started discussions with engineers at MFC on getting approvals to deploy the ANL sampler in HFEF and started drafting the F&OR for our M4 milestone.

3.3.4 MOLTEN SALT PM/NMA

[ANL] Held multiple calls with INL regarding installation of a new sensor into HFEF. The sensor at Argonne is being prepared for shipment to INL before the end of January to ensure timely installation into the hot cell.

[INL] Coordinating with ANL to have the multi-array sensor ready for deployment in the ER. The new hardware should be received at INL before the end of January and will go into the HotCell prior to the aircell shutdown at the end of January/beginning of February. The gas control panel for the triple bubbler is still awaiting new mass flow controllers. 1 of 3 have arrived at INL and the final 2 are expected to ship in late December. Once the parts are here, the current mass flow controllers will be exchanged for the new ones with expanded capability which should reduce plugging. Recent findings indicate that O2 may be coming in through the bubbler lines which has increased plugging. meetings are ongoing to get to the bottom of that. Engineers at MFC are tweaking the design of the OR Voltammetry probe in preparation for transferring it into the HFEF hotcell.

3.3.5 ELECTROCHEMICAL & AQUEOUS REPROCESSING ACOUSTIC INTERROGATION

[LANL] The summary report on acoustic sensor development was completed along with a supplementary manuscript.

3.4 Domestic Safeguards Education

3.4.1 NMAC TRAINING

[LANL] The review of the FY23 course material was completed, and feedback was compiled. A team meeting to start coordinating FY24 course logistics was held, and the schedule review is underway so that module modifications can be performed accordingly.

[ORNL] Completed review/comment on current course. Currently discussing module update assignments. Room/facility for June 2024 course offering at ORNL reserved.

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] N. Stauff was nominated by the office of DOE-NE4 to the NEA Expert Group on the Small Modular Reactor Economics

[INL, ANL] Prepared for the campaign approach review meeting the first week of December. Held discussions with counterparts in other programs to line up collaborations with the MSR campaign (for technology road mapping), GAIN and LPO (for cost studies and pathway mapping), and NETL (for FY-24 DAC activities).

4.2 NUCLEAR ENERGY SYSTEM PERFORMANCE (NESP)

4.2.1 MAPPING INFRASTRUCTURE DEVELOPMENT NEEDS TO SUPPORT NUCLEAR REACTORS FOR NET ZERO EMISSIONS

[INL] Developed the approach for the task and started gathering references for review. Identified staff at each lab who will take part. Drafted the slide deck for use at the campaign approach review meeting.

4.2.2 NUCLEAR ENERGY SUPPORT TO NEGATIVE EMISSIONS TECHNOLOGIES

[ANL] N. Stauff organized a panel session of "Net Zero and Beyond: How Nuclear Energy Could Power Negative Emissions Technologies" in the ANS winter meeting held in Washington D.C. in November 2023. In the panel session, N. Stauff gave a presentation entitled "How can nuclear energy couple with negative emission technologies?"

[ANL, INL] Started the kick-off meeting of the NET with nuclear energy activity.

[BNL] Continued literature surveys on negative emissions technologies

4.2.3 JOINT DEVELOPMENT OF MOLTEN SALT REACTOR TECHNOLOGY ROADMAP

[INL] Developed plans to execute the work scope. Prepared slides for the approach review meeting. Established team at partner labs to support this work.

4.2.4 TRANSMUTATION DATA REPOSITORY DEVELOPMENT

[BNL] Ongoing activities include installing locally the 2018 transmutation library package and making it available for BNL staff working on this project. An interim private GitLab repository is being used at BNL for these purposes.

4.2.5 FUEL CYCLE CATALOG ACTIVITIES

[SNL] The FY23 deliverable for this work package, a memo summarizing the status the Nuclear Fuel Cycle Options Catalog, was completed, and submitted on time.

4.2.6 QUICK TURN-AROUND STUDIES

[ANL] A whitepaper, entitled "Cost of SWUs thrown away in Once-through Fuel Cycle," was written and submitted to the NE-4 office.

Various once-through advanced reactors utilize HALEU to achieve their design goals (such as a higher burnup), but the used fuels are thrown away. In this whitepaper, the SWU cost for enriching natural uranium (NU) up to the residual U-235 content in the used HALEU fuel was evaluated to measure the value of the residual U-235. The SWU cost is proportional to the residual U-235 content. For instance, the evaluated SWU cost is 10 – 3,300 million $/GWe-year for the used HALEU fuels having a residual U-235 content of 7.0 – 19.6 %.

4.2.7 ACTIVITIES FROM FY23 –

[INL, BNL] Completed a milestone on technology road mapping and submitted it to NTD and FM.

Hays, R., Cuadra, A., & Todosow, M. (2023). A technology roadmap for fuel cycle capabilities to support advanced reactor deployment. Idaho National Laboratory, Idaho Falls. INL/RPT-23-75247

[ORNL] The ORNL team with the ANL team completed the Activity #1, Task #1 report while incorporating the feedback from a peer reviewer and the Deputy NTD. It is currently undergoing a final review by the NTD before submission to the federal manager.

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

4.3.1 QUANTIFYING DEPLOYMENT COST REDUCTION STRATEGIES FOR ADVANCED REACTORS

[INL] Held meetings with staff at INL and ANL to develop plans to support the work scope and the software release of ACCERT. Also, presented a conference paper on cost reduction opportunities beyond niche remote markets.

4.3.2 ASSESSMENT AND MITIGATION STRATEGIES OF NUCLEAR EARLY ADOPTER RISKS

[INL] Met with staff from ANL to discuss approach. Began drafting white paper to document approach and preliminary findings. Drafted the slide deck for the approach review meetings. Contacted external reviewers to confirm willingness to review project work.

4.3.3 QUANTIFYING SOCIOECONOMIC IMPACTS OF ELECTRICITY GENERATION TECHNOLOGIES

[INL] Met with staff members to finalize research plans. Continued to perform the literature review. Presented approach at the campaign approach meetings. Collaborated with staff at GAIN on LCOE related impacts and participated in GAIN discussion with LAZARD on how to reflect socioeconomics into system impacts. Analyzed data on renewable energy from NREL's JEDI model for input/output analysis.

4.3.4 TECHNO-ECONOMIC CAPABILITIES DEVELOPMENT

[ANL, INL] N. Stauff gave a presentation entitled "Nuclear energy cost evaluation" with a brief introduction to ACCERT and the Cost Basis Report in the panel session "Integrated Energy Systems Modeling and Simulation Challenges" of the ANS Winter meeting held in Washington D.C., November 2023.

[INL] A. Abou-Jaoude, et al., "Assessing the Impact of Mass Production on Microreactor Costs", ANS Winter Meeting, Washington D.C., USA, November 2023

[ANL, INL] Attended the GAIN's Advanced Reactor Costs meeting on Nov. 16, 2023, and provide the reactor O&M costs by E. Hoffman. In the follow-up meeting on Nov. 27, the SA&I campaign activities and concerns on the advanced reactor costs were.

[**INL**] Held meetings with staff at INL and ANL to develop plans to support the work scope and the software release of ACCERT. Submitted a pull request with ACCERT to incorporate Design A cost equations into the software. Also, held several meetings with EPRI to continue finalizing the document on the Generalized Code of Accounts.

4.3.5 ADVANCED FUEL CYCLE COST BASIS REPORT IMPROVEMENTS

[INL] Submitted M4 on 11/14/23. Hansen, J., Larsen, L., Guaita, N., Hoffman, E., Williams, K., Price, L., Kalinina, E., Ottinger, C., (2023). FY23 Annual Report on Updates to the Advanced Fuel Cycle – Cost Basis Report. INL/RPT-23-75608

[INL] Met with staff from ANL and SNL to discuss plans for FY24. Many relevant modules of the CBR to industry needs are in consideration of updating. Initiated preliminary work to assess data availability to support updates.

4.3.6 SUPPORT DOE NE IN INTERNATIONAL ENGAGEMENTS

[INL] Participated in initial meetings led by NE-HQ to set up requested support for the Czech Republic's cost modeling efforts, narrowing the scope to review of their August 2023 Nuclear Case Study that assesses options for new nuclear deployment to minimize projected energy shortages due to phase-out of coal power.

[INL] Participated (virtually) in 39th Meeting of the NEA Expert Group on Advanced Fuel Cycle Scenarios. The topic of the meeting was results of the study on the international benchmarking activity for cooperative management of transuranic material. In preparation for this, reviewed draft report.

4.3.7 EVALUATION OF SA&I CAPACITY EXPANSION TOOLS

[BNL] Continue to explore features of the TIMES GUI

4.3.8 COMPLETE COAL TO NUCLEAR GUIDEBOOK

[INL] Staff working with DOE NE communications staff to coordinate public release of milestone submitted in October with public release of easy-to-read version drafted by communications staff.

4.4 SA&I Advanced Nuclear Fuel Availability (ANFA) Support

4.4.1 HALEU MARKET DEVELOPMENT AND HALEU PROGRAM LIFECYCLE

[INL, ANL, ORNL] Held meetings to discuss approaches to the activity. Met with staff from relevant labs to develop approach. Prepared slides for Campaign review meetings and presented approach.

4.4.2 FRONT-END FUEL CYCLE COST PROJECTIONS

[INL, ANL, ORNL] Held meetings to discuss approaches to the activity. Met with staff from relevant labs to develop approach. Prepared slides for Campaign review meetings and presented approach.

4.4.3 Cost Comparison of Domestic-Focused Once-Through vs Recycle for Advanced Reactors

[ANL, INL, ORNL] Held meetings to discuss approaches to the activity.

4.4.4 Summary report on the roles of nuclear energy in US decarbonization

[ANL, INL, ORNL] Held a kick-off meeting. Multi-lab team participated in various planning meetings to provide input data into this task from EMANES and ANFA #2 activities. Coordinated efforts from ANFA activities 1 – 3 with ANFA 4. Presentation slides for the approach review meeting were completed to address how the problem defined in the work scope would be solved.

For more information on the Systems Analysis and Integration contact Brent Dixon (208) 526-4928.