INL/EXT-20-59617

Nuclear Fuel Cycle and Supply Chain (NFCSC) Technical Monthly July FY-20

July 2020

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 July FY-20

1. ADVANCED FUELS CAMPAIGN

1.1 Advanced LWR Fuels

1.1.1 LWR Fuels

[INL] ATF Fuels Process Development Improvement, FT-20IN02020101 Piping and exhaust duct runs were completed. (M. Cole)

1.1.2 LWR Core Materials

[LANL] Preparations are underway for high dose irradiation on FeCrAl using heavy ions. (S. Maloy)

[LANL] Tensile testing on specimens cut from tubes is planned to be completed at room temperature, 300 and 600C during August/September timeframe. (S. Maloy)

[LANL] Hot cells have opened now and we are working to ship an irradiated FeCrAl specimen to the FIB for analyzing the microstructure. (B. Eftink)

1.1.3 LWR Irradiation Testing & PIE Techniques

[INL] During the month of July, the Advanced Test Reactor (ATR) had to shut down due to high filterable solids in the primary coolant system on June 3, 2020. The chemistry issue was resolved, ATR began reactor start up on July 1, 2020, but the startup was secured due to an electrical relay failure. The relay was replaced, and ATR reached full power July 2, 2020 and finished Cycle 168A 7 July 22, 2020. ATF-2 reached ~304 effective full power days (EFPDs), ATF-2B1 (configuration with general electric boiling water reactor type pins in Tier 3 and 4 positions) reached ~120 EFPDs, and ATF-2B2 (configuration with three new twelve-inch long pressurized water reactor (PWR) type fuel pins with coated O-Zirlo cladding and UO_2 fuel for Westinghouse in the Tier 5/6 position and four new six-inch long PWR type fuel pins with M5 cladding and UO_2 fuel for Framatome in the Tier 1 position) reached ~60 EFPDs of irradiation. Reconfiguration of ATF-2B2 is not anticipated until Cycle 171A outage during the third quarter of FY-22 after ATR core internals change out (CIC). CIC is scheduled to start April 2021. (G. Hoggard)

[INL] Project and administrative resources remain dedicated to vendor projects with Framatome and General Atomics. The existing ATF-1 Framatome project remains on track. Receipt inspection of the rodlets from Framatome has completed. The ATF-SiC General Atomics project is progressing through its conceptual design effort. Other efforts supported by this work package such as NDMAS development and Implementation continue to make progress. (C. Murdock)

[INL] Three mounts from rodlet ATF-OF1 have been shipped to Oak Ridge National Laboratory for advanced PIE. This rodlet, sponsored by ORNL, contained several discs of UO2 between different FeCrAl alloys, restrained in H-cups. The purpose is to study the potential interaction between LWR fuel and candidate ATF iron-based cladding material. (F. Cappia)

1.1.4 LWR Fuel Safety Testing

1.1.4.1 LWR Modeling & Analysis

[INL] BISON models for selected ATF-2 rods have been successfully developed and are being executed. Fuel performance metrics and phenomena of interest identified by modeling include: (1) fission gas release up to 20%, (2) peak fuel temperature up to 1800C, and (3) Cladding creepdown. (P. Medvedev)

1.2 Advanced Reactor Fuels

1.2.1 AR Irradiation Testing & PIE Techniques

[INL] FAST-1 assembly work continues to make progress toward completion. FAST-1 inner capsules were inspected and loaded into outer capsules. The outer capsule end caps have been welded on and are awaiting inspection. Weld development for the final weeper hole welds is now in process. As-built analysis and paperwork is also being concurrently performed. Program milestones have been revised to account for COVID operations shutdown.

AFC-OA experiments completed irradiating in the ATR for cycle 168A-1. Preparations for the 168B-1 cycle are making progress and nearing completion.

NDE of AFC-4C rodlet 5 has been completed. HFEF is down for unplanned maintenance until August 14. The next activities to be worked will be on the GASR. Design. (C. Murdock)

1.3 Capability Development

1.3.1 CX TREAT Testing Infrastructure

[INL] During the past month data was collected on all the samples using a spatial filter on the pump beam. Significant progress was made on a model and methodology for extracting accurate diffusivity from measurements. A paper is being prepared and will be submitted to a high impact journal. (R. Schley)

1.3.2 CX Halden Gap Activities

1.3.2.1 TREAT

[INL] Assembly of the ATF-RIA-1-A capsule was completed and it was shipped from the Materials and Fuels Complex to the Transient Test Reactor. Welding of end caps on the B and C rodlets was initiated and radiography completed on the welds. (L. Emerson)

[INL] Milestone M2FT - 20IN020206022, “Complete preliminary design of TREAT LOCA test,” was completed on 6-29-2020. This milestone marks the 60% design completion point in the design process. The LOCA-SERTTA test vehicle is scheduled to undergo commission testing in FY-21. This test vehicle will establish LOCA testing capability at the TREAT reactor and is an important piece of nuclear fuels testing moving forward. (D. Dempsey)

[INL] Engineering calculations final reviews were completed and were issued in the document management system. The experiment final design review was held and a design review closure letter was issued. (L. Emerson)

[INL] In-pile testing of sensors in TREAT resumed after the TREAT outage and virus shutdown. Currently 6 sensors are loaded in the TREAT coolant channels to evaluate performance in TREAT including completion of irradiation of advanced manufactured dosimeters for the NEET ASI program. (T. Pavey)

[INL] Phase 1 qualification testing and demonstration of the ring tension and axial tube tension test fixtures were completed. This included characterization of the fixtures such as friction effects that support later data analysis. Began preparations for the next phase of qualification. (M. Bybee)

[INL] X-ray of several experiments at TREAT were completed. A comparison between x-ray and neutron radiography is in process. (T. Pavey)

[INL] Fabrication of all of the major pieces of equipment necessary to perform remote handling (assembly/disassembly) of the MARCH-SERTTA device in the hot cell was completed. Assembly and Phase 1 qualification/demonstration activities were initiated. (M. Bybee)

[INL] Fabrication of both the circumferential and welding under pressure systems continued. The electrical feedthrough design continued following a design review. Work on the Phase I/II procedures for end cap welding, welding under pressure, and weld prep continued. (M. Cole)

[INL] The PEP is close to being complete. The WBS and schedule have been prepared. The closure plate procurement is progressing. The vendor has ordered most of the materials and is fabricating components. The final ECARs are being completed for the closure plate analysis. Fabrication of hardware for the ATRC run is moving forward. Specifications for long lead hardware have been drafted and are out for review. (T. Maddock)

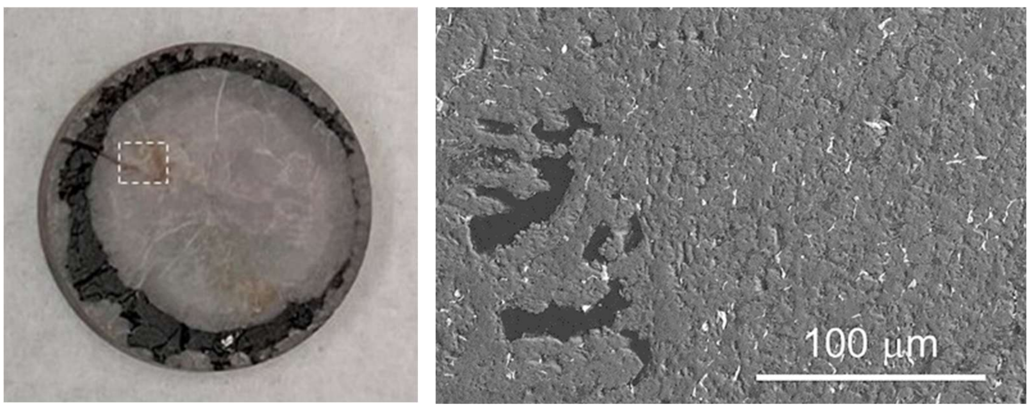
For more information on Fuels contact Steven Hayes (208) 526-7255.

2. MATERIAL RECOVERY AND WASTE FORMS DEVELOPMENT

2.1 MRWFD SUPPORT – WASTE FORMS AND OFF-GAS CAPTURE

2.1.1 Advanced Waste Forms and Processes

[ANL] Tests with three developmental iron phosphate materials made at PNNL with either the low or high extremes of added Fe_2O_3 were subjected to ASTM C1308 tests to assess the intrinsic durabilities and to PCT to assess the effects of solution feedback. The two materials with low amounts of added Fe_2O_3 are phase separated, as shown for a specimen of material DPF-43 in Figure 1a, although the compositions of the phases are very similar (except the Li contents were not measured and are expected to differ). The bright features in the photomicrograph in Figure 1b of an interior region near a crack are unincorporated rare earth element oxides. Specimens have been prepared for XRD analyses of the materials.



(a) (b)

Figure 1. (a) Photograph of test specimen of DPF-43 and (b) microstructure near crack.

Analyses of the microstructures of HIPed iodide waste forms indicate both AgI and pure silver are exposed at the surface and these will interact electrochemically. Electrochemical tests with separate AgI and silver electrodes were conducted in preparation of experiments to measure galvanic coupling with silver and with 316L stainless steel representing the HIP can. The reduction of Ag^+ in AgI to metallic silver will enhance the AgI dissolution rate and increase the solubility limit of I^-. The range of redox conditions in which reductive dissolution occurs must be known for modeling waste form performance. Figure 2 shows the results of separate potentiodynamic scans with an AgI electrode performed with increasing potentials (anodic, black trace) and decreasing potentials (cathodic, red trace). The cathodic PD may indicate oxidation of silver impurities at about 0.5 V before the corrosion potential is reached at about 0.2 V and shows complex behavior at lower potentials as the Ag^+ in AgI is reduced. The corrosion potential in the anodic trace (at -0.1 V) is significantly lower due to the reduction of AgI that occurred when the scan was initiated at about -0.3 V. The anodic scan shows high currents as the potential increases to about 0.6 V as the silver that was generated when the measurement was initiated is oxidized. The response at even higher potentials shows the oxidative dissolution of AgI to form iodate. These scans show the interactions of AgI and silver qualitatively. Tests with pure silver and pure AgI electrodes will be used to quantify the effect of the relative areas of AgI and silver exposed on a IWF material surface on the corrosion potential and AgI dissolution rate. (W. Ebert)

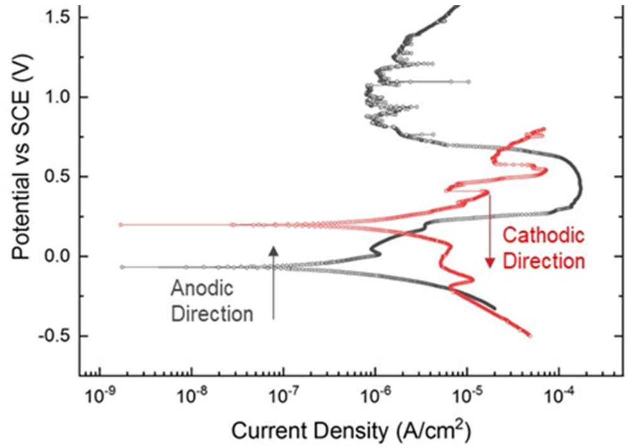


Figure 2. Comparison of anodic (black) and cathodic (red) PD scans of AgI in pH 4 solution.

2.1.2 Sigma Team Off-Gas

[INL] INL participated with ORNL in preparing report on time for a Level 3 ORNL milestone M3FT-20OR030107032 titled, "Prepare and submit a draft report on requirements for treating off-gas arising from processing of advanced reactor UNF reprocessing," on July 31, 2020. Drafting of this report included developing and performing a plan to estimate radionuclide decontamination factors (DFs) to meet regulatory air emission limits, and assessing if the current prototypical electrochemical reprocessing facility inherently already can be expected to achieve those DFs by virtue of the reprocessing equipment and argon hot cell design. This evaluation was modeled after prior studies that evaluated off-gas treatment requirements for aqueous reprocessing.

Two radionuclides (Kr-85 and H-3) thought to be volatile during aqueous reprocessing are also expected to be volatile during electrochemical reprocessing. The need to add control technologies specific to these two radionuclides depends on such factors as used fuel burnup and post-reactor cooling, loss of H-3 from the fuel into the reactor coolant while in the reactor, used fuel processing rate, design and operation of the hot cell gas cleanup system, reprocessing facility location and design. Iodine-129, thought to be volatile during aqueous reprocessing with associated high DFs exceeding 1,000, is expected to be less volatile during electrochemical reprocessing because of its expected speciation in less volatile chemical forms. Carbon-14, also thought to be volatile during aqueous reprocessing, is not present in the example metallic used fuel that was used in this study, and so DFs for C-14 were not evaluated.

A long-duration, long-chain iodide adsorption test that was started on June 30 for M3FT-20IN030107011 "Evaluate the retention of long-chain organic iodides on silver functionalized mordenite and aerogel (joint report with ORNL)" was continued. This non-radioactive test is planned to run continuously for about 2,000 hours to evaluate iodine chemisorption on silver zeolite from gaseous iodobutane at a concentration of nominally 1 ppmv in a simulated aqueous reprocessing vessel off-gas stream. This will augment previous organic iodide chemisorption tests performed at INL and ORNL. (J. Law)

[PNNL] PNNL is working on collecting the data on newly engineered MOF materials at different temperatures with pure gas. (P. Thallapally)

[ORNL] The milestone M3FT-20OR030107032 titled, "Prepare and submit a draft report on requirements for treating off-gas arising from pyroprocessing," was completed on time. This report seeks to determine how current US regulations may limit the release of volatile radionuclides from an electrochemical-based UNF reprocessing facility. The analysis performed is based on a generalized electrochemical reprocessing concept and is not facility-specific, resulting in conclusions that may be broadly applied across multiple electrochemical reprocessing implementation scenarios. The potential for volatile radionuclide release from individual unit operations is to be assessed using thermodynamic modeling. These results are used to inform air dispersion modeling, which prescribes the level of radionuclide mitigation that may be required. Multiple scenarios are examined to assess the effects of throughput, volatile radionuclide speciation, and facility design choices on mitigation requirements. Potential mitigation strategies are identified and include recommendations for process design and off-gas capture, as well as identification of key knowledge gaps that may impact efficient volatile radionuclide management. (S. Bruffey)

[ORNL] Support was provided on the task to evaluate the retention of long-chain organic iodides on silver functionalized mordenite and aerogel (a joint report with INL). A thin bed of AgZ was held at 150°C and exposed to a dry gas stream containing 5 ppm iodobutane. The sorbent was saturated after 26 days with a total weight gain of 80 m/g AgZ. This test will be compared to similar testing at iodobutane feed concentrations of 42 and 10 ppm. (S. Bruffey)

2.2 ZIRCEX

2.2.1 Material Recovery Pilot Plant

[INL] Two tests were completed in the month of July. Both tests were designed to simulate the elutriation of uranium from the hydrochlorinator (HC) vessel. CeO_2 was used as a simulant for uranium and 200g were placed in the HC vessel in alumina bed media. Nitrogen was used as the fluidizing gas. The first test was run for an hour and approximately 115g of material was collected from the UOx filter. The second test was also run for an hour using the existing, approximately 85g, sample from the previous test. The second test resulted in an additional 15g of material in the UOx filter. These tests will help determine the operating conditions and time required for the actual elutriation of uranium out of the HC. (M. Warner)

[ORNL] Work continued on the task to complete U_3O_8 elutriation tests in fluidized bed. System assembly was completed in July (Figure 1). Test plans were revised based on conversations with MRPP personnel. This effort has been slowed by an unexpected and extended facility outage. (S. Bruffey)

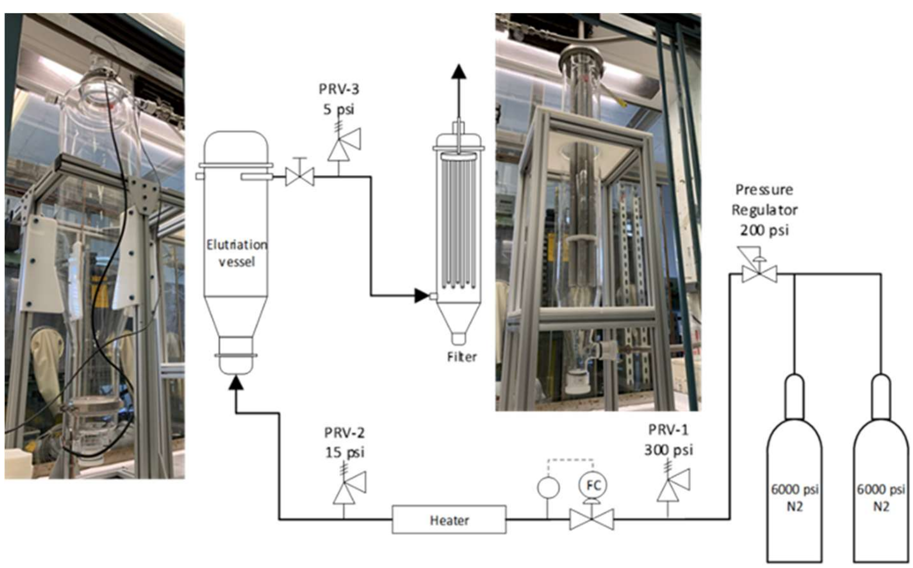


Figure 3. Elutriation test apparatus and flow diagram.

2.2.2 Polishing & Solidification (Extraction, Conversion, Downblending)

[ANL] In order to validate the extraction efficiency across various contactor rotor designs, extraction tests are planned to measure the D-values for extraction of scandium (as a uranium surrogate) with TBP. The simulant UREX feed will consist of scandium dissolved in 7-8 M nitric acid and the organic feed will consist of TBP in dodecane. Scandium concentration in the feed and contactor outputs will be measured via ICP-MS. Fabrication of contactor components has been completed, hardware has been procured, and assembly is expected to be completed in August.

As part of on-going work to update AMUSE for flowsheet development, work continued on the conversion of speciation and distribution coefficient code to the MATLAB environment. Integration of the existing MATLAB dynamic mass balance with this revised code will assure matching data structures between the two codes. Incorporation of user-defined anions for the mass balance required changes to the HTML input format and parser. The distribution coefficient equations for those anion systems would need to be developed as needed.

Calculations were performed with AMUSE (Excel version 3.5.4) to adjust the reference flowsheet and improve separations with respect to product polishing goals. Poor ruthenium separation was resulting in ~10,000 ug Ru per g U in the product polishing product, while the design standard is 1 ug Ru per g U in final HALEU product. Ruthenium impurities are undesirable because Ru-103 and Ru-106 contribute to total gamma activity of HALEU fuel produced.

By lowering the feed acidity from 2.0 M to 0.7 M, the decontamination factor (DF) for Ru relative to U was found to improve by ~200% (from 844 to 2594). DFs for other species were largely unchanged (variations of +/-1%) with the exception of Np and Pu, which were both significantly improved by the lower feed acidity (+12% and +583%, respectively). Since these changes were only able to reduce the Ru content in the Product Polishing product to ~3,200 ug Ru per g U, further modifications to the flowsheet are being evaluated in order to meet the 1 ug Ru per g U specification. (C. Pereira)

2.2.3 Early Design of Engineering Scale Demonstration

[INL] The conceptual design for the HZD Engineering Scale Demonstration continues to progress. A draft study comparing various hydrochlorinator designs has been completed which will allow the project to select a design that will improve optimize element loading and filtration. Project personnel continue to compile the Demonstration Execution Plan, Risk Register, and the Technology Development Road Map. (T. Burnett)

2.3 EBR-II Accelerated Processing

2.3.1 Aqueous Processing

[ORNL] We have continued to make progress with benchmarking calculations to predict the selectivity of the $Am(H_2PO_2)_3 + Eu(H_2PX_2)_3 \rightleftharpoons Am (H_2PX_2)_3 + Eu(H_2PO_2)_3$ reaction, with X=S, Se, and Te. We have optimized all geometries in these reactions with RI-MP2 and SSC(ano)/aug-cc-VTZ basis-set/pseudopotential combination. Results of these calculations show that the reaction releases more energy as we move down the periodic table from X=S to X=Te. We have also been working to calculate single-point energies at these geometries with higher accuracy, both using the larger aug-cc-pVQZ basis set towards the complete-basis-set limit, as well as with DLPNO-CCSD(T). Finally, in the interest of computational economy, we have been searching for a density functional that produces similar results to those from RI-MP2 and DLPNO-CCSD(T) calculations. Currently, we are working with the PBE, M06, and wB97X-D3 functionals. In the coming month, we expect to complete the high-accuracy single-point calculations as well as the additional DFT calculations. (V. Bryantsev)

Milestone M3FT-20OR030401022 was completed. Milestone completion notice as well as the PowerPoint presentation describing the scientific findings of this project have been sent to the program manager. Synthesis of 0.8 moles of a single diastereomer of Me_2TDDGA has been completed. Within the next week or two, the isolated material will be sent to collaborators at INL, where it will be diluted using organic diluent. The solution of (R,S)-Me_2TDDGA will then be distributed among the project participants who will carry out the research-specific tasks. Overall, the synthesis of (R,S)-Me_2TDDGA was scientifically and technically challenging, since due to high reactivity of the chemicals and the potential hazards associated with the rapid evolution of byproduct (hydrogen gas) the known synthesis path could not be undertaken. A creative solution was designed to overcome the associated challenges and this in turn resulted in an invention disclosure, (Invention Reference 202004611, I.D. number 81920055 " Telescoped and Efficient Synthesis of Diglycolamides") that has been elected to be filed as a provisional patent. The newly developed method has broad applicability as it can be used to prepare symmetrical and unsymmetrical diglycolamide derivatives more efficiently. In comparison to the known synthesis method, the new synthesis scheme allows to reduce the number of steps (from 4 to 2) and the overall yield is nearly doubled. Further process intensification and optimization could open up a commercially viable pathway towards synthesis of the title compound. (S. Jansone-Popova)

[PNNL] The fifth CoDCon flowsheet test was successfully completed, fulfilling milestone M3FT-20PN030401039. As in the previous tests, the flowsheet was designed to achieve a target U/Pu ratio or 7/3 in the Pu-containing product. This fifth test also had the following new objectives: (1) routing of the technetium added to the feed solution to the process raffinate, and (2) complete extraction of neptunium and routing the neptunium to the Pu-containing product. Analyses of the many samples taken during the test are in progress. PNNL personnel involved in performing the test were Gabe Hall, Jarrod Allred, Susan Asmussen, Forrest Heller, Amanda Lines, Sergey Sinkov, Sam Bryan, and Gregg Lumetta. Candido Pereira (ANL) helped with designing the flowsheet that was tested. (G. Lumetta)

[PNNL] A paper titled, "Sensor fusion: comprehensive real-time, on-line monitoring for process control via visible, NIR, and Raman spectroscopy," was published in the peer-reviewed journal ACS Sensors. The abstract of this paper is presented below.

- On-line monitoring based on optical spectroscopy provides unprecedented insight into the chemical composition of process streams or batches. Amplifying this approach through utilizing multiple forms of optical spectroscopy in sensor fusion can greatly expand the number and type of chemical species that can be identified and quantified. This is demonstrated herein, on the analysis of used nuclear fuel recycling streams: highly complex processes with multiple target and interfering analytes. The optical techniques of visible absorbance, near infrared absorbance, and Raman spectroscopy were combined to quantify plutonium (III, IV, VI), uranium (IV, VI), neptunium (IV, V, VI), and nitric acid. Chemometric modeling was used to quantify analytes in process streams in real-time and results were successfully used to enable immediate process control and generation of a product stream at a set composition ratio. This represents a significant step forward in the ability to monitor and control complex chemical processes occurring in harsh chemical environments.

The authors of this paper are Amanda Lines, Gabe Hall, Susan Asmussen, Jarrod Allred, Sergey Sinkov, Forrest Heller, Neal Gallagher, Gregg Lumetta, and Samuel Bryan. (G. Lumetta)

[PNNL] Design for the dual beam spectrometer was completed for the Self-Calibrating, On-line, Real-time Composition Analysis (SCORCA) sensor in fulfillment of milestone M3FT-20PN0304010315. This represents an important step towards advancing on-line monitoring capabilities for harsh environments. Procurement of the instrument has been initiated and experimental plans are being developed to collect the data needed to develop and evaluate modeling approaches for real-time reference collection and correction to overcome common challenges anticipated in nuclear materials processing. Amanda Lines, Sam Bryan, Heather Felmy, and Hope Lackey (G. Lumetta)

[ANL] Experimental work on engineering scale cell being modified to demonstrate co-deposition of 1 kg mixture of U and REE resumed after Lab-mandated pause in mid-March. Existing heat shields and connections were cleaned and installation of large-scale cathode/crucible assembly and newly designed daisy chain of anode baskets initiated. Plan for testing new equipment, calibrating operation parameters for new design, and suite of demonstration tests was prepared and reviewed.

The schedule for the planned webinar round table to discuss aspects for developing an iron phosphate waste form for salt waste from electrorefining operation to be co-hosted with Brian Riley (PNNL) was finalized. Two 4-hour meetings will be held to discuss the state of knowledge regarding phosphate glass waste forms, preliminary work conducted within the MRWFD campaign, and other aspects regarding the production, handling, and disposal of salt-based waste form. Subject matter experts from national laboratories, universities, and industry will make presentations. Information discussed in the meetings will be used to support the development of a "roadmap" report to be issued in December. (W. Ebert)

For more information on Material Recovery and Waste Forms Development contact Terry Todd (208) 526-3365

3. MPACT CAMPAIGN

3.1 Campaign Management

3.1.1 NTD & Management Support

[LANL] MPACT NTD, CAM, and Federal Program Manager held calls with MPACT PIs after the MPACT annual meeting to develop prospective plans for FY21. These activities were folded into the MPACT Planning Package presentation.

3.2 MRWFD/Advanced Nuclear Safeguards and Security Research

3.2.1 MSR Safeguards – MSDR Signatures

[ORNL] Interim report still in review on the preliminary signatures work.

3.2.2 Microcalorimetry Consulting

[LANL] Work focused on preparing the LANL Instrumentation Development JNMM paper in support of the 2020 milestone. An initial draft was submitted and the revisions are being finalized. An important result will be measurements of ER salt samples from INL. These samples are now packaged at INL and in process for final LANL approvals. Commissioning of the INL cryostat system is on schedule for cold testing to begin in August.

3.3 Safeguards and Security Supporting Technologies – Echem

3.3.1 Microfluidic Sampler

[ANL] Lab work on this project was partially restarted in July. Efforts were focused on changes to the system design and procedures to address new regulations.

3.3.2 Bubbler for Measuring Density and Depth of Molten Salt

[INL] Installed bubbler in HFEF and monitored the bubbling process during batch 5 in the ER.

3.3.3 OR Voltammetry

[INL] Continued to run OR voltammetry in hot cell, set up new potentiostat, getting ready for continuous running.

3.3.4 ER Voltammetry

[ANL] ER sensor operations have begun in the INL electrorefiner. So far, results look as expected with good discrimination of uranium and plutonium responses in the salt. Once the data files are able to be transferred to ANL, further examination of the results will take place.

3.4 Safeguards and Security – Milestone 2020 – Echem

3.4.1 Advanced Integration - Methods

[LANL] Submitted the AI 2020 milestone paper for review by the MPACT project leader. All deliverables are on track.

3.4.2 Safeguards Facility Models

[SNL] The final report and JNMM paper have been drafted. The final runs are taking some significant computational time, but the milestone should be met on time. There may be a need to push back the SAND report slightly to allow more time to finish all the runs.

3.4.3 Milestone 2020 Coordination

[SNL] Eight out of the nine planned JNMM articles have been sent to SNL for review and tie into the overall special issue. Currently in the process of providing review comments, checking for SNT, and pulling information for the safeguards modeling and overview paper. So far, there should not be any problem in submitting all the papers to JNMM by mid-September.

3.4.4 Security Facility Models

[SNL] The JNMM article has been drafted and is in a near final state. Additional scenarios will be tested and included in the final SAND report.

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, ORNL, PNNL, SNL**] Discussed the potential work scopes in FY 2021 with the lab leads and federal manager and developed the presentation file for the NE-4 planning meeting in early August.

4.2 NUCLEAR ENERGY SYSTEM PERFORMANCE (NESP)

4.2.1 Trial Application of TSRA and ACCERT Capabilities to Micro-reactor Designs

[**ANL, INL**] Submitted the report entitled "*Trial Application of TSRA and ACCERT Capabilities to Microreactor Designs*" by T. K. Kim, et al. This report is the deliverable in fulfillment of the Level 2 milestone, M2FT- 20AN120102011 under the work package of "FT-20AN12010201 - Nuclear Energy System Performance (NESP)-ANL." Following is the executive summary of the report:

- The SA&I campaign has developed the Technology and System Readiness Assessment (TSRA) process and Algorithm for the Capital Cost Estimation of Reactor Technologies (ACCERT) for assessment of the technology maturity and capital cost of nuclear reactor systems, respectively. The usefulness of both capabilities has been demonstrated through trial applications to several nuclear systems and associated fuel cycles. In this work, the trial application of the TSRA and ACCERT capabilities has been extended to microreactors that are currently under development. Through interactions with microreactor vendors and the Microreactor campaign of DOE-NE, the SA&I campaign has performed the evaluations on the Holos Quad gas-cooled microreactor and INL's Design-A heat-pipe microreactor. The TRLs of most technology elements of both microreactors are TRL 5 or higher because both reactors have adopted commercial or mature technologies for quick demonstration/commercialization. However, the overall system readiness levels (SRLs) are SRL 4 or SRL 3 for Holos and Design-A, respectively due to some specific systems having lower maturity. The direct overnight cost estimates are currently preliminary and rough-order-of-magnitude. The estimated direct overnight costs are in the range of $104M–$119M (or 10,400 – 59,500 $/kWe). In this work, it was recognized that the vendor's involvement was crucial, and authors greatly appreciate HolosGen LLC. Without sharing the design information of Holos reactor, the assessments of technology maturity and direct overnight capital cost analysis performed in this work would not have been meaningful.

[**BNL**] Provided input on INL Design-A heat-pipe reactor, and reviewed final ANL deliverable report *Trial Application of TSRA and ACCERT Capabilities to Microreactor Designs*

4.2.2 Factors Impacting Nuclear Energy Share

[**ANL**] The impacts of natural gas prices, negative electricity price events, flexible operation on the role of nuclear energy in a future electricity power market were reviewed and the draft description was written in this month.

4.2.3 FCDP Development for Specific Advanced Reactors

[BNL] Provided a revised "Technology Data File" for PWR fuel with FeCrAl cladding for the ORNL FCDP for "PWR-UOX with FeCrAl Cladding" as an example of Accident Tolerant Fuel (ATF).

4.2.4 Maintain/Update of Fuel Cycle Catalog

[SNL] We received two data packages containing the data for two nuclear fuel cycles and a technology data file containing the data for a reactor, the small modular reactor. The data contained in these files is being entered into the Nuclear Fuel Cycle Options Catalog. In addition, we worked on modifying the PWR UOX technology datafile to reflect the accident-tolerant fuel used in one of the fuel cycle options, FeCrAl-clad fuel.

4.2.5 Transition Analysis Studies and Tools Development

[**ORNL**] The analysis and write up of the uncertainty quantification, sensitivity analysis, and optimization study using Cyclus was completed. The write up was reviewed internally and submitted to ANL for inclusion in their milestone due later this year.

[**ANL**] The coupled DYMOND/ORIGEN/DAKOTA script was re-run with modified input definitions based on DAKOTA development team feedback, and preliminary results show good agreement with one another. The inability to include scenarios in which there are fuel shortages in DAKOTA's multivariate post-processing schemes has led to investigations into using surrogate models to take these "failed" DYMOND scenarios into account.

[**ORNL**] In addition to the report sections being completed, unit tests were generated for the tools used in the UQ/SA/Optimization study and released the inputs / scripts to ORNL GitLab. Access is by invitation only.

[INL] Reviewed UQ results from collaborators.

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

4.3.1 Improvement of ACCERT Algorithm

[**ANL**] A draft outline of the M3 deliverable report was sent to team members. Writing was begun on the draft report. The trial use of ACCERT for a separations plant was completed and a draft writeup completed. Many of the algorithms are applicable, but to advance ACCERT for use for separations plants will require the development of additional algorithms for the specialized equipment. The same would seem to apply for fuel fabrication facilities. A proposed algorithm for estimating indirect costs for power plants in the early phase of design development was proposed. It will require judgment on the relative complexity, benefits of factory fabrication, and construction time, but should provide a reasonable guide on objectives to reduce cost until a cost loaded project schedule can be estimated or other more involved estimates can be developed for a specific project.

[INL] INL staff reviewed draft documents of ACCERT algorithm report and provided comments and suggested edits to ANL colleagues.

4.3.2 Daily Market Analysis of Load Following and Storage Impacts

[**ANL**] In this month the ANL team has been conducting Capacity Expansion types of analyses using A-LEAF code based on ERCOT market to assess the conditions required in terms of policies, price of natural gas, and capital cost of nuclear, to enable future deployment of large baseload and flexible nuclear units. This analysis shows there are economic incentives to deploy nuclear power plants at low capital cost ($2000/kW, assuming current price of natural gas of $2.56/MMBTU) or at elevated price of natural gas ($5.50/MMBTU, with assumed nuclear capital cost of $4000/kW), if a carbon tax of $40/ton is implemented. Analysis also indicates that both baseload and load-following nuclear units are valuable to the market under system conditions where new nuclear units are built. Even more reduction in capital cost of nuclear would be required for it to be deployed under PTC, ITC, and no-policy scenarios. No new nuclear is ever deployed under RPS scenario. Detailed values results are being documented in Milestone report.

[BNL] Worked on updating MARKAL model - provided scenario results for the following:

- base case with low natural gas price (all cases below are sensitivities of this base case)
- Carbon tax $40/tCO2
- Carbon tax $40/tCO2 + low nuclear capital cost ($2000/kWe)

4.3.3 Cost Basis Report Enhancements

[**ANL, INL**] Completed the activity of "Cost Basis Report Enhancement" and submitted the report titled "Annual Report on Improvements and Updates to the Advanced Fuel Cycle – Cost Basis Report" by Hansen et al. This report is the deliverable in fulfillment of the Level 3 Milestone, Document on Cost Basis Report Enhancements, M3FT-20IN120103021, under work package "FT-20IN12010302 Economic and Market Analysis for Nuclear Energy Systems (EMANES) – INL." This annual report details the activities of the fiscal year 2020, describes new areas of research to expand the applicability of the Advanced Fuel Cycle – Cost Basis Report (AFC-CBR), and for convenience of the reader, summarizes the activities of 2018 and 2019 that relate to this year's activities. The three activities listed below, accomplished this year, represent major updates for the next release of AFC-CBR: 1) Updated cost basis of fuel fabrication modules, 2) Enhanced methodology for more robust economic applications, and 3) Revised approach for the more frequent publication of new data.

4.3.4 Regional and Global Analysis

[PNNL] Began analysis and writing of second journal paper on the carbon value of nuclear power plant lifetime extensions in the United States. This paper focuses specifically on the United States and the contribution of existing nuclear reactors for mitigating climate change. The value of lifetime extensions is quantified using multiple nuclear sensitive cases of nuclear lifetimes with and without policy efforts to limit global climate change to 2-degree C.

4.3.5 Lessons-Learned from LWR Deployment History

[INL] INL staff met with co-authors for LWR history journal paper. Then continued work on consolidating the LWR history report submitted to DOE with the internal INL report on LWR history with a global perspective.

4.3.6 Adaptation of OR-SAGE for NES Analysis

[ORNL] Work is well under way in compiling the FY20 letter report summary on the "Adaptation of OR-SAGE for NES Analysis." The report covers FY20 additions to the Oak Ridge Advanced Fuel Cycle Logistics Environment (ORACLE) tool including the decision analysis system, a material movement module, and a plant replacement simulation.

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

5. JOINT FUEL CYCLE STUDY ACTIVITIES

Status of the Integrated Recycling Test:

- Limitations in overhead handling and transfer ports at HFEF severely impacted performance of IRT and Critical Gap experiments.
- The fifth electrorefining test with ~4.0 kg irradiated LWR fuel was initiated in July.

Status of Critical Gap activities:

- An investigation of improved Oxide Reduction System electrode designs with porous shrouds and planar electrodes continued.
- The preparation LCC-sized urania crucibles for use as an alternative crucible material continued.

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 completed processing award checks for the 2020 Innovations Awards winners.

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

University Research Alliance prepared press releases on behalf of the 2020 Innovations Awards winners. Winners' university department heads, advisors, and newspapers are among those who are formally notified of their achievement.

University Research Alliance prepared the 2020 Innovations Awards announcement for 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 were submitted by the ANS extended 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.