INL/EXT-20-58262

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

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CONTENTS

FIGURES

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

1. ADVANCED FUELS CAMPAIGN

1.1 Advanced LWR Fuels

1.1.1 LWR Fuels

[INL] The planned work packages were issued, materials ordered, and the necessary electrical modifications in FCF were completed. Due to the COVID-19 issue, no further progress can be made as most of the craft resources are in a stay-at-home status. (M. Cole)

[LANL] EDS and EBSD maps of UO_2-UB_4 composites were collected using an EDAX system on an Inspect SEM. From the EBSD maps, a bimodal grain distribution can be observed with a significant number of grains around 1 μm in diameter while other grains featured diameters around 10 μm. The analysis did not indicate the existence of an orientation relationship between the UO_2 and UB_4 grains in the examined composites. Further tests are planned for the UO_2-UB_2 composites upon restart of normal operations. (D. Frazer, E. Kardoulaki)

1.1.2 LWR Core Materials

[LANL] The C26M tube has been cross-sectioned and initial EBSD analysis was performed on pressure resistance weld on C26M tubing that was received from Global Nuclear Fuels. (S. Maloy)

[LANL] Tensile specimens have been EDM machined from the C26M tube for performing mechanical testing along its axial length. (S. Maloy)

[LANL] A cost estimate is being developed to determine costs to clean out hot cells to place in a safe configuration. A plan is in place to ship HFIR neutron irradiated FeCrAl samples to the MSL for TEM characterization when normal operations resume. (B. Eftink)

1.1.3 LWR Irradiation Testing & PIE Techniques

[INL] During the month of March, the Advanced Test Reactor completed powered axial locator mechanism (PALM) Cycle 167A. ATF-2 is not irradiated during PALM cycles, so it remained at 244 effective full power days (EFPDs) and ATF-2B1 (configuration with general electric boiling water reactor type pins in Tier 3 and 4 positions) remained at 60 EFPDs of irradiation. The ATF-2B2 configuration was assembled and installed into ATR. The ATF-2B2 configuration includes 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. The ATF-2B2 configuration includes the first fueled 12-inch long fuel pins. (G. Hoggard)

[INL] Preparations to ship all legacy ATF-1 capsules, 16 in total, are making progress toward a possible May shipment from ATR to HFEF. Remaining project and administrative support are dedicated to vendor projects with Framatome and General Atomics. The existing ATF-1 Framatome project is on track with both design and analysis. The assembly operations are now curtailed due to COVID-19. The new ATF-SiC General Atomics project kicked off and is targeting completion of a conceptual design effort at the end of the current fiscal year. (C. Murdock)

[INL] The cask containing the first batch of ATF-2 pins was unloaded in HFEF. Seven of the ATF-2 baseline pins made of UO2-Zr-4 were contained in the cask. These pins will be used as reference pins against which the performance of the new ATF concepts will be evaluated. A picture taken during cask unloading in the hot cell is shown in Figure 1. (F. Cappia)

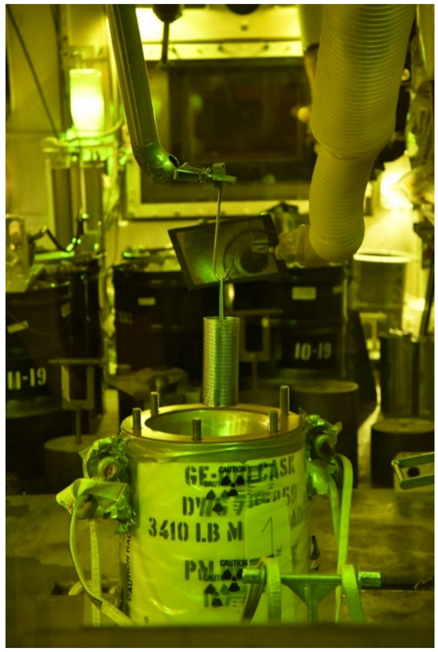

Figure 1. Non-destructive examinations (NDEs) of the ATF-2 pins started. The NDEs include visual examinations, neutron radiography, profilometry, and gamma scanning.

1.1.4 LWR Fuel Safety Testing

1.1.4.1 LWR Modeling & Analysis

[ORNL] Fuel performance modeling assessments of silicon carbide cladding, with a focus on the stress and deformation associated with neutron irradiation effects are ongoing. Prior computational modeling of silicon carbide BWR channel box behavior is now in press. Full citation is:

G. Singh, J.P. Gorton, D. Schappel, B.S. Collins, Y. Katoh, N.R. Brown and B.D. Wirth, "Impact of control blade insertion the deformation behavior of SiC-SiC channel boxes in BWRs," Nuclear Engineering and Design 363 (2020) 110621. (B. Wirth)

[BNL] Initial scoping studies to estimate the impact on reactor performance and safety characteristics of coating UN fuel pellets to mitigate the fuel/coolant interactions in LWRs have been completed. The analyses were performed with the TRITON lattice code for a detailed model of a reference 17x17 Westinghouse fuel assembly and the fuel with fully enriched N-15. Approximately 15 candidates proposed by LANL for the coatings have been evaluated. Initial studies assume 20 μm thickness for the coatings applied to the surface of the pellet; fuel pellet outer radius and cladding radii are fixed at the reference values. (M. Todosow)

[BNL] Scoping studies have continued to estimate the impact on reactor performance and safety characteristics of the use of high-assay LEU (HALEU), i.e., enrichments above 5 w/o, in a commercial PWR to increase burnup. The initial analyses are being performed with the TRITON lattice code for a detailed model of a reference 17x17 Westinghouse fuel assembly with UO2 fuel and enrichments of 4.95, 6.0, and 7.0 w/o. Discharge burnup and cycle length along with fuel and moderator temperature reactivity coefficients and control coefficients (soluble boron and control rods) are being estimated. The discharge burnup and cycle length are estimated using the linear reactivity model (LRM) for 1, 2, 3, and 4 batch fuel management. (M. Todosow)

1.2 Advanced Reactor Fuels

1.2.1 AR Irradiation Testing & PIE Techniques

[INL] The AFC-OA cycle-specific physics analysis is complete and administrative documentation is issued. The reconfiguration work in the canal is complete and the AFC-OA experiments are prepared for the next ATR cycle 168A-1, with anticipated startup April 14. AFC-IRT1 (C3 & C4) and AFC-4C (C5) completed irradiations in the ATR at the conclusion of the 166B-1 cycle and were shipped and received at HFEF March 5. FAST-1 fuel fabrication work is complete. Remaining capsule component fabrication work was completed. FAST-1 assembly work made good progress and was on track until operations were curtailed due to COVID-19. (C. Murdock)

1.3 Capability Development

1.3.1 CX TREAT Testing Infrastructure

[INL] The replacement control computer has not yet been received. Data has been collected from the parallel PTR setup using three techniques: time domain, frequency scan, and spatial scan. So far, the data has been repeatable. Modeling of the data is ongoing. (R. Schley)

1.3.2 CX Halden Gap Activities

1.3.2.1 TREAT

[INL] The first two rodlets were welded and radiography performed. Capsule bodies were machined to remove some manufacturing defects causing uncertainty in welding parameters. Additional pressure sensors were ordered and work to assess the viability of a new type of pressure transducer is underway. Capsule instrumentation was threaded through the first flanges and is ready for assembly. Additional physical assembly work is on hold for INL Min. Safe + status. (L. Emerson)

[INL] Collaboration with Oregon State University began on a Burst Disc assembly to be used in the LOCA-SERTTA test vehicle. This work will help solve a critical problem in the design, which is how to trigger the capsule blowdown at the desired time during the transient irradiation. (D. Dempsey)

[INL] All team members were moved to telecommuting status. This has slowed the design process some, but it is still proceeding. The design team worked with the hot-cell facilities to finalize experiment shielding concerns. Final drawings are being drafted, and final experiment safety analysis is in progress. Neutronics analysis has begun the technical checking process. This is expected to be followed shortly by the thermal hydraulic and structural analyses. (L. Emerson)

[INL] A prototype custom "low-temperature" pyrometer measurement was built to extend high speed, non-contact temperature measurement that will enable capturing initial low-temperature behaviors in experiments. A concurrent testing data package was drafted to implement after the TREAT outage. (T. Pavey)

[INL] Axial tension and ring tension specimens have been designed, and their machining ordered via the machine shop. Compliance samples have been designed and ordered for fabrication. The Phase 1 document for the ring compression, ring tension, and axial tension tests has been issued in ECR. The mechanical testing frame was moved to a new location and the load cell has been reassembled. The plane-strain tension fixture has been assembled for Phase 1 hands-on activities at RCB. (M. Bybee)

[ORNL] The Level 3 milestone (M3FT-20OR020206091) titled, "Report Summarizing Boiling Transition (Dry-out) Testing of FeCrAl Cladding," due March 13, 2020, was successfully completed. A novel experiment was developed using the severe accident test station located at Oak Ridge National Laboratory to simulate cyclic dry-out conditions that can occur in boiling water reactors. The experiment utilizes the same equipment for conducting loss-of-coolant burst experiments on non-irradiated light water reactor cladding. Briefly, internally pressurized fuel cladding is cycled in a flowing steam environment at approximately 15–20°C/sec from 300°C to 650°–800°C. C26M was found to last up to 54 300°–650°C cycles (at which point testing was concluded without failure); Zircaloy-2 cladding failed after 16 cycles. Multiple tests were conducted, and a hoop stress-specific dry-out failure map was constructed (Figure 2). These tests showed that FeCrAl cladding would be expected to have significantly improved performance in BWR ATWS events or other scenarios with significant duration of dry-out. (K. Kane [ORNL], S. Lee [UTK], B. Pint [ORNL], N. Brown [UTK])

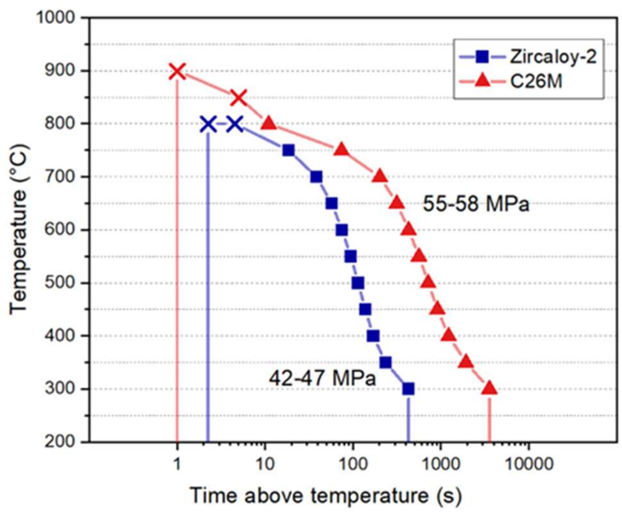

Figure 2. Dry-out hoop stress map obtained by combining failure criteria from C26M burst at 55 and 58 MPa hoop stress cycled at 300°–700°C and 300°C–800°C, respectively, and Zircaloy-2 burst at 42 and 47 MPa hoop stress, cycled at 300°–650°C.

[INL] Hardware was rechecked in preparation for SO testing completion at TREAT. Penn State sent the counter prototype to BCTC for testing. The X-ray system is laid out and ready for testing. The Laboratory Instruction (LI-974) was completed for operations of the X-ray. The ECAR was completed for counting of the Gamma pin for Power Coupling Factor for future MARCH-SERTTA testing. The fluxwire and fission wire documents for TREAT were completed. (T. Pavey)

[INL] Work was completed on a CRADA with the JAEA. The CRADA is in place and work has begun on a TREAT irradiation project involving fuel specimens previously irradiated in EBR-II. This is a joint USA and Japanese project. (D. Dempsey)

[INL] Design reviews were completed for the MARCH-SERTTA in-cell-handling equipment. The table and pit liner are ready to install for the HFEF Decon Cell window 5D and are ready to install. Fabrication is being completed on the pallet to move the pit liner. Work is underway drafting documentation for the in-cell equipment and lifting fixtures (15-Cask Related). Security cans are being fabricated by American Fabrication. Lifting fixture materials are on hand and fabrication is underway. Preparations are underway for a cask-cart dry run at HFEF as well as for MSA/CRA. (M. Bybee)

[INL] The project team has completed everything that can be completed on the de-fueling activities. Once personnel are allowed to return to MFC, the actual de-fueling, removal of oxide layer, and other activities can be completed. The contract to design and fabricate the end-cap welding system was awarded to AMET. Design on the welding under pressure system and electrical and gas feedthrough system is also progressing. (M. Cole)

[INL] The closure plate contract has been sent out for bid. The design review is in process and the comment period is nearly complete. The experiment tube and design for the out-of-core equipment continue to progress. Booster element analysis is on schedule and will be complete by the milestone date. (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 Molten Salt Waste Forms

[ANL] Long-term tests initiated in FY-19 with two iron phosphate materials DPF-280 and DPF-336 that were made with low and high salt waste loadings have been completed and initial analyses of corroded surfaces show differences in the corrosion behaviors. Figure 3 shows a high magnification SEM photomicrograph of DPF-336 after the ASTM C1308 test, which is covered with a fairly thick coating of secondary phases and several rectangular crystallites. The crystallites are fairly uniformly sized and much smaller than the crystals formed in the waste form. The measured composition of the crystallites is Al_{15} P_{12} Fe_5 Sr_4 O_{64} and the substrate material is Al_5 P_6 Fe_{25} O_{62}, in atom percent. Elemental maps for Al and Sr and a composite map of Al, P, Fe, Sr, and O are also provided in Figure 3. The Ca is sequestered by the crystalline phase, but higher Ce concentrations are measured in the Fe-rich substrate. Initial analyses of solids recovered from the ASTM C1285 PCT show the formation of surface layers having a clay-like appearance. Those analyses were paused due to the lab moving to limited operations and then closure due to the state-imposed stay-at-home order. (W. Ebert)

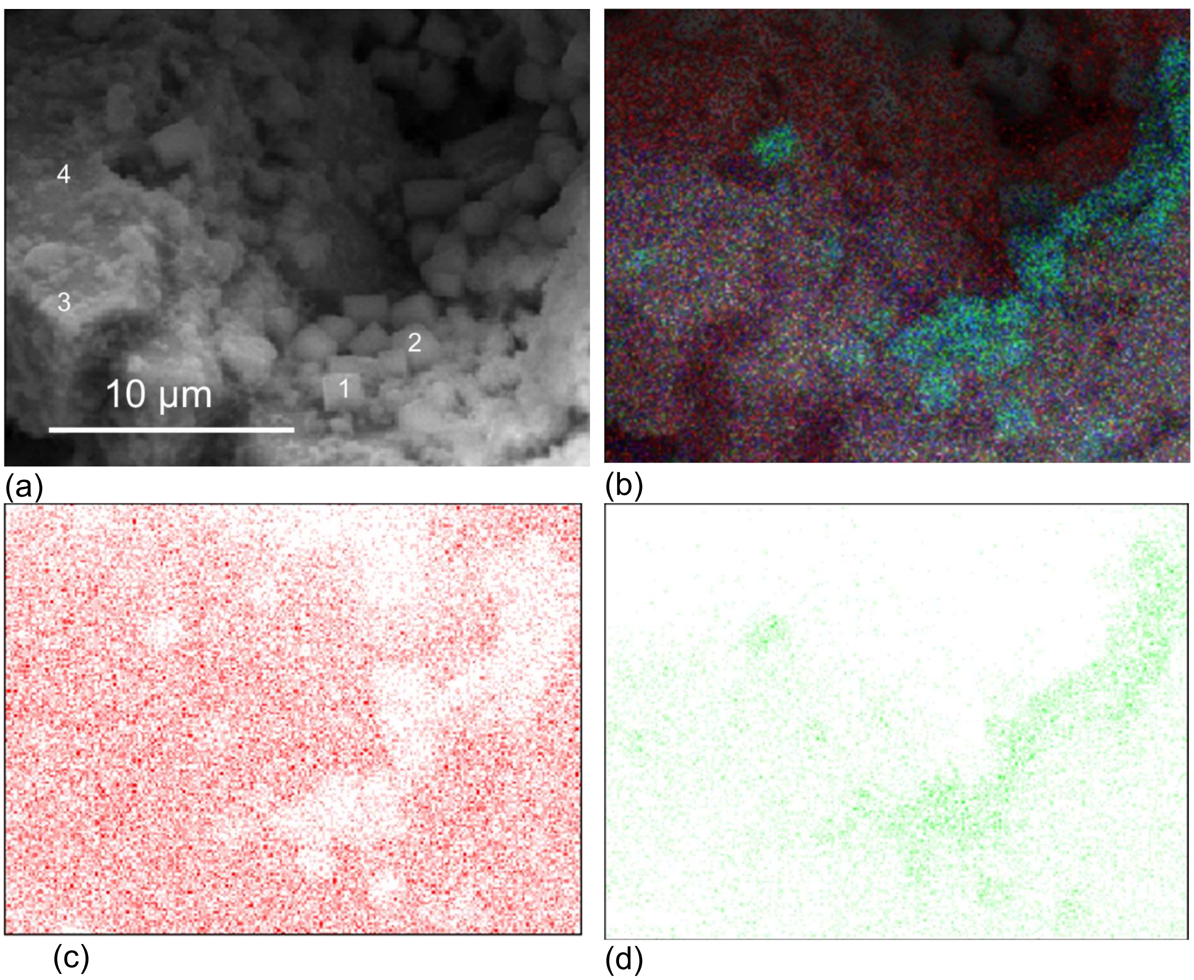

Figure 3. (a) SEM photomicrograph of corroded surface of DPF-336 after ASTM C1220 test and elemental maps of (b) composite, (c) Fe and (d) Sr.

2.1.2 Off-Gas

[INL] The Milestone M3FT-20IN030107014, titled "Support assessment of the off-gas system requirements/conceptual design for pyroprocessing of metallic UNF," is progressing. ORNL has updated a draft report outline, and the literature review was completed in the January 2020. The Level 4 milestone is being used to identify candidate used advanced reactor metal fuel(s), pyroprocessing rate(s), and features of the pyroprocess that could evolve gaseous emissions.

[INL] Coordination has been completed via teleconference with ORNL for starting a long-chain iodide adsorption test for M3FT-20IN030107011. The start of the planned test is delayed until after we can re-enter the laboratory to begin this test. (J. Law)

[ORNL] Biweekly teleconferences to support the assessment of the off-gas system requirements/conceptual design for processing of advanced reactor metallic UNF have been initiated, with the first held on March 25 with participants from ORNL and INL. A rough outline of the assessment has been revised based on new work package scope and a reference case is being identified. (S. Bruffey)

[ORNL] Two teleconferences with participants from ORNL and INL were held on March 24 and March 31 to coordinate testing efforts for the evaluation of the retention of long-chain organic iodides on silver functionalized mordenite and aerogel. INL has agreed to perform deep-bed testing with iodobutane at conditions aligned with previous INL testing. ORNL has agreed to perform thin-bed testing with iodobutane and iodododecane to better understand concentration and chain length effects on the adsorption of organic iodides by AgZ. (S. Bruffey)

[ORNL] Two extended VOG tests were initiated on May 31, 2019. The first challenged a deep bed of Ag^0Z with ~50 ppb I_2 (balance dry air) at 150°C. The second challenged a deep bed of Ag^0Z with ~150 ppb CH_3I (balance dry air) at 150°C. Both tests were concluded on March 2 after 9 months online. Samples have been sent for analysis at ORNL's High Flux Isotope Reactor. (S. Bruffey)

[ORNL] Four-factor factorial experiments have been completed to characterize the adsorption of I_2 by AgZ and CH_3I by AgZ, resulting in a total of 16 thin-bed tests. This represents a substantial amount of new information on adsorption of iodine by AgZ in conditions representing those of the dissolver off-gas. Samples have been sent to ORNL's High Flux Isotope Reactor to determine the final iodine loading of the sorbents from each of the 16 tests. (S. Bruffey)

2.2 Innovative Process Support – Aqueous Processing and Molten Salt Chemistry

[INL] Experimental work to design and build a new test loop for radiation studies (Figure 4) is nearing completion. (D. Peterman)

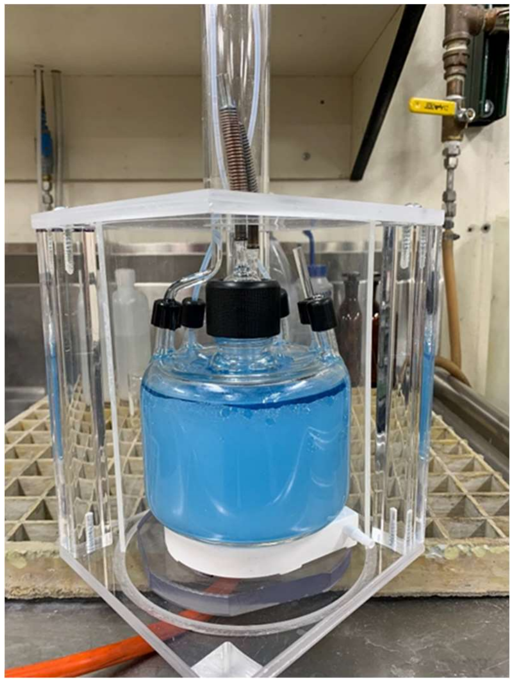

Figure 4. New test loop for radiation studies.

[ONRL] During March 2020, experimental work to enhance the heat capacity of molten salts was started. Two eutectic mixtures ($ZnCl_2$-KCl, T_{mp} = 220C, and $MgCl_2$-KCl, T_{mp} = 420C) were chosen as working media. The individual salts were preliminarily purified by distillation and eutectic mixtures were obtained by melting the required amount of correspondent salts. The hollow carbon nanospheres and zeolite nanoparticles were chosen to produce colloid solutions with eutectic mixtures. The preparation of salt compositions with different nanoparticle content is in progress. A high-temperature calorimeter has been installed and adapted to measure the thermophysical properties of salt eutectics. (S. Dai)

[ONRL] Invention Disclosure ID#: 202004611, "Telescoped and Efficient Synthesis of Diglycolamides," by Santa Jansone-Popova and Ilja Popovs was submitted on March 20, 2020. (S. Jansone-Popova)

[ORNL] One of the two starting materials for the synthesis of (*R,S*)-mTDDGA has been prepared on 0.8 kg scale (2-bromo-N,N-didecylpropanamide). The reaction was carefully planned and carried out in 12 L round-bottom flask. Isolation of the product involved filtration and solvent evaporation, washing the product with water to remove traces of 2-bromopropanoic acid (Figure 5). Product was obtained as an orange oil, in >95% purity based on the ^{1}H NMR spectroscopy data, and >80% yield.

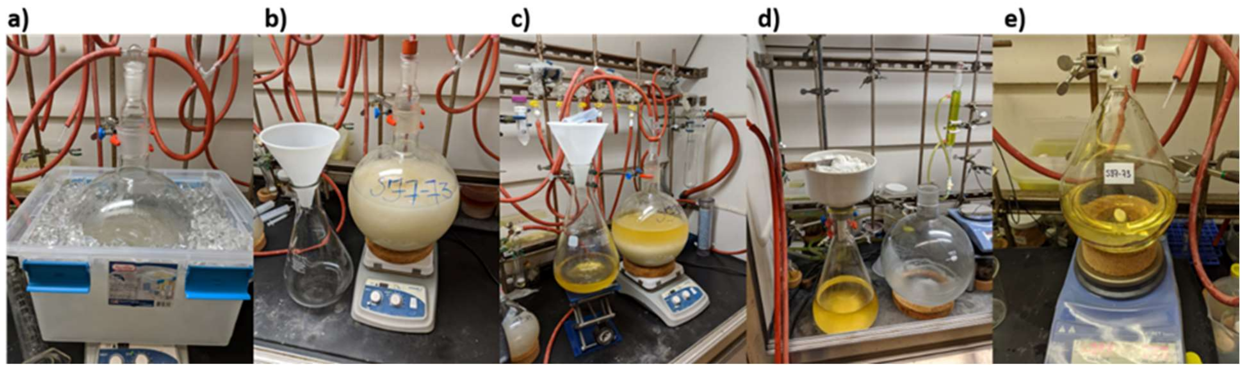

Figure 5. Synthesis of 2-bromo-N,N-didecylpropanamide: (a) a 12 L reaction flask is cooled in ice/water bath prior to the addition of 2-bromopropionyl bromide; (b) the reaction mixture after the addition of 2-bromopropionyl bromide; (c) decantation of the reaction

- Scale-up of the other starting material (*N,N*-didecyl-2-hydroxypropanamide) will be initiated in April. (S. Jansone-Popova)

[PNNL] The journal article titled, "Evolution of acid-dependent Am^{3+} and Eu^{3+} organic coordination environment: effects on extraction efficiency," was published in the peer reviewed journal *Inorganic Chemistry*. The abstract for this paper follows.

- Coordination of trivalent lanthanide and actinide metal ions by lipophilic diglycolamides and phosphonic acids has been proposed for their separation through extraction from aqueous nitric acid solutions. However, the nature of M^{3+} coordination complexes in these combined solvent systems is not well understood resulting in low predictability of their behavior. This work demonstrates that a combination of *N,N,N′,N′*-tetra(2-ethylhexyl)diglycolamide (T2EHDGA) and weakly acidic 2-ethylhexylphosphonic acid mono-2-ethylhexyl ester (HEH[EHP]) in *n*-dodecane exhibits a complicated extraction mechanism for Eu^{3+} and Am^{3+}, which continuously evolves as a function of the aqueous phase acidity. At low aqueous phase nitric acid concentrations, M^{3+} ions are primarily extracted *via* exchange of the phosphonic acid proton and coordination with HEH[EHP]. At high aqueous phase nitric acid concentrations, HEH[EHP] remains protonated, and M^{3+} are transported to the organic phase by coextraction of nitrate anions from the aqueous phase, thus forming complex species with T2EHDGA. At moderate acid regimes, both ligands participate in coordination of M^{3+} and show a synergistic relationship resulting in the considerable enhancement of the M^{3+} transport into the combined solvent system than the simple sum of the individual extractants. The observed synergism is caused by differences in organic phase M^{3+} speciation and has a significant impact on the performance of the organic solvent. Distribution studies with Eu^{3+} indicate nominally two or three T2EHDGA ligands participate in metal extraction in the presence of the phosphonic acid, while nominally three diglycolamide ligands participate in the presence or absence of the phosphonic acid respectively. While synergistic behavior has been observed in many solvent extraction processes, this system demonstrates a clear correlation between continuously changing organic speciation of M^{3+} and its transport into the organic solvent. This manuscript reports the spectroscopic characterization of the organic phase M^{3+} species by infrared, X-ray absorption, and visible spectroscopies. Spectroscopic evidence indicates a mixed ligand complex, *i.e.,* a ternary complex at the moderate acid regimes where the greatest degree of synergism is observed. Differences in synergistic extraction of Am^{3+} and Eu^{3+} at the low acid regime were observed indicating their dissimilar extraction behavior.

[PNNL] The authors of this paper are Gabriel B. Hall, Vanessa E. Holfeltz, Emily L. Campbell, Daria Boglaienko, Gregg J. Lumetta, and Tatiana G. Levitskaia. (G. Lumetta)

[ANL] Biweekly phone calls were held with INL and PNNL PIs to discuss the plan for initial reviews of the available literature on international advanced flowsheets in order to evaluate their relevance to a simplified flowsheet design and eventually frame an approach for development efforts. (C. Pereira)

[ANL] Electrochemical tests quantifying the effect of impurities were completed. Results of electrochemical impedance spectroscopy measurements made during tests with added Li_2O were analyzed to assess Zircaloy corrosion and oxide formation. (W. Ebert)

[ANL] Installation of new parts made to demonstrate co-deposition at the kilogram scale was initiated. Results from previous tests conducted to determine target operation conditions are being re-evaluated and documented. (W. Ebert)

2.3 ZIRCEX

2.3.1 Material Recovery Pilot Plant

[INL] The initial tests in the MRPP were designed to determine the instantaneous reaction rate of Zircaloy with HCl, the overall reaction rate of Zircaloy with HCl, and to determine if alumina or silica bed material in the hydrochlorinator provided a better rate.

[INL] The MRPP has now run several tests with alumina bed material and one with silica bed material. See the table below for the initial results:

	Starting weight(g)	Instantaneous rate (kg/hr)	Overall reaction rate (kg/hr)
Zircaloy in 100% HCl – Alumina bed material	1966.44	1.14	1.15
Zircaloy in 100% HCl – Alumina bed material – Repeat test	1954.33	1.15	1.36
Zircaloy in 100% HCl – Silica bed material	1964.16	0.75	Not yet determined

[INL] While the bed material does not chemically contribute to the reaction taking place, the movement of the bed facilitates heat removal and gas distribution. We believe the difference in the density and particle size of the silica are contributing to the lower reaction rate. We have not been able to open the hydrochlorinator vessel to retrieve the remnants of the Zircaloy piece, if there are any, to calculate the overall reaction rate. Based on the instantaneous rate, we are assuming it will be quite a bit lower as well. Once we do know the overall reaction rate with the silica bed material, we will be able to decide on which type of media to use for our future tests. (M. Warner)

[ORNL] Parametric studies of zirconium and aluminum hydrochlorination have been completed using a prototypic hydrochlorination system. These studies allowed the collection of kinetic data under conditions indicated to be best-case for fluidized bed conversion. Analysis of results is ongoing. Preparations to study the hydrochlorination of aluminum in the presence of uranium metal are ongoing. Experiments have been rescoped away from use of clad fuel segments and will instead use uranium metal and aluminum coupons to simulate unirradiated clad fuel. Testing will be performed to determine the potential for carryover of the UCl_4 as an adduct. (S. Bruffey)

[ORNL] An experimental apparatus for the U_3O_8 Elutriation task has been designed based on discussions with INL. Major components have arrived from the manufacturer. The elutriation bed has been set up in its stand and mounted in the hood. Components for the filter assembly have arrived and the stand is being constructed. Work orders have been placed to connect the high-pressure gas lines and to install the power supply for the gas heater. A commissioning test with tungsten oxide powder is planned once the major components are installed. (S. Bruffey)

2.3.2 Polishing and Solidification

[INL] The Uranium Polishing Laboratory Scale demonstration completed Milestone M2FT-20IN03020301, which was to complete characterization of the solutions and solids produced during the first campaign to evaluate the effectiveness due March 31, 2020. A publicly releasable Executive Summary was produced and approved thru the Lab Review System, INL/EXT-20-57790. The goal of the lab-scale project was to demonstrate the capability to polish repurposed EBR-II metal HALEU product, producing purified HALEU oxide powders suitable for thermal reactor fuel fabrication. The laboratory-scale HALEU polishing process consists of four primary unit operations: dissolution, solvent extraction (SX), precipitation, and calcination.

[INL] The polishing process removes residual fission products (FP), transuranic (TRU) isotopes of plutonium and neptunium, and stable metallic impurities (MI), predominantly zirconium. In this process the EBR-II material is converted into a liquid uranyl nitrate solution amenable to purification via solvent extraction. A modified uranium extraction (UREX) flowsheet was designed for this application using the Argonne Model for Universal Solvent Extraction (AMUSE), targeting > 99% recovery of U at >99.9% purity. The purified uranyl nitrate solution was precipitated as uranyl peroxide tetrahydrate (UO_4•$4H_2O$) through the addition of hydrogen peroxide. The uranyl peroxide precipitate was converted to both uranium oxide (U_3O_8) and amorphous uranium trioxide (UO_3) as finished purified oxide products as shown in Figure 6. Both forms are suitable feedstocks for the production of UO_2 powders used in fuel fabrication processes.

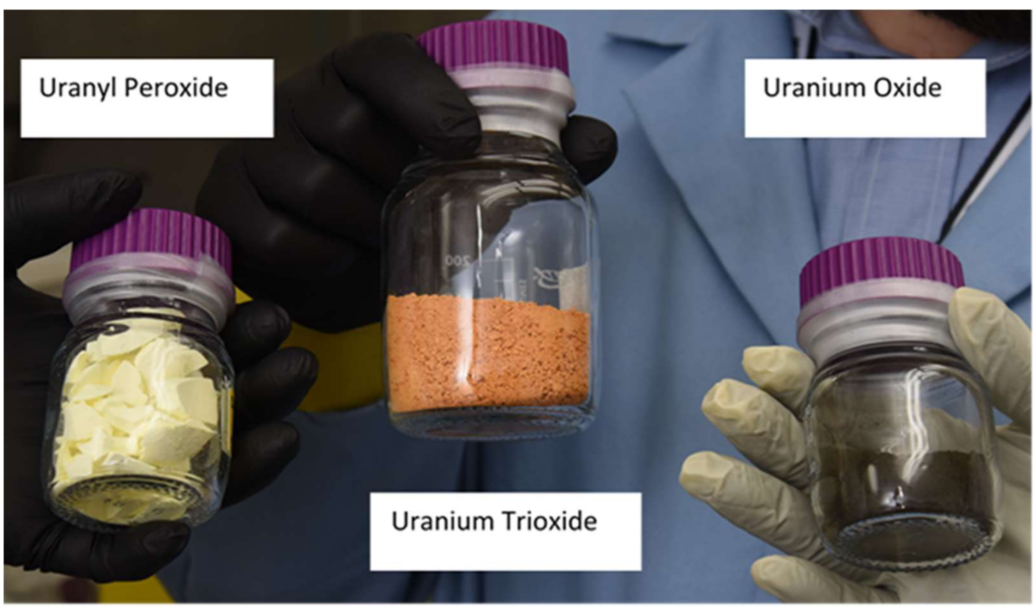

Figure 6. Uranyl peroxide precipitate converted to both uranium oxide (U_3O_8) and amorphous uranium trioxide (UO_3) as finished purified oxide products.

[INL] Product samples (UO_3 and U_3O_8) indicated a high degree of purity, with U being the only detectable species.

[INL] Contact dose rates were measured for the EBR-II material and purified U materials including the $UO_4 \cdot 4H_2O$ precipitate, UO_3, and U_3O_8. Note the excellent agreement between calculated theoretical dose rates for pure U_3O_8 using the specified HALEU isotopic composition and the actual measured dose rate of the recovered U_3O_8.

HALEU material normalized dose rates per Kg of material.

Material	Sample Size	Dose Rate per Kg
HALEU Runt	1.746 Kg	583 mR Hr^{-1} β^- 6.3 mR Hr^{-1} γ
$UO_4 \cdot 4H_2O$†	50 g	6.8 mR Hr^{-1} β^-, γ
UO_3†	175 g	2.2 mR Hr^{-1} β^-, γ
U_3O_8†	780 g	0.9 mR Hr^{-1} β^-, γ
U_3O_8 Calculated*	1 Kg	0.053 mR Hr^{-1} β^- 0.908 mR Hr^{-1} γ

†Chemical purity between $UO_4 \cdot 4H_2O$, UO_3, and U_3O_8 are identical. Dose rate variances originate from self-shielding effects. Dose rates represent a select few product samples.
*Theoretical dose rates calculated using MicroShield and Varskin software. Calculations based on 1 Kg U_3O_8 at 80.11% U-238, 19.75 % U-235, and 0.14% U-234. Calculated U_3O_8 dose rate assumes fresh, unirradiated uranium and daughter decay products are not present.

[INL] Process recoveries are broken down by unit operation and overall final oxide product recovered, with conversion including both precipitation and calcination.

Process uranium recoveries for laboratory-scale polishing.

Dissolution	Solvent Extraction	Conversion	Final Oxide Products
100%	>99.8%	94.0%	89.9%*

**Final oxide mass discounts U from an unprocessed conversion batch and various samples.*

[INL] Of the original EBR-II mass, 89.9% was recovered in oxide form. The final process recovery for the polishing campaign is estimated at approximately 94%. (C. Williams)

2.3.3 Early Design of Engineering-Scale Demonstration

[INL] Several equipment options and drafts of locating those systems in the overall facility cells were received and informally reviewed. Quantities of HALEU to be produced from various downblend percentages and materials (DU vs. NU vs. LEU) were evaluated. A technology risk assessment (TRA) for **[INL]** Zircex process was completed in anticipation of including this assessment and associated options to reduce technology risk in the Technology Development Roadmap, which is on schedule for the M2 April release. (T. Burnett)

[ANL] The evaluation of components that require revisions in order to meet HALEU fuel specifications, with the aim of improving their separation in the product polishing flowsheet continues. A literature search for extraction data on tin did not locate usable D-value measurements for tin in the nitric acid/TBP/paraffinic diluent system but did establish a basis for assumptions about tin's extraction behavior in the product polishing flowsheet.

[ANL] The conversion of SASPE (speciation and D-value equations) to MATLAB continues to provide the ability to more easily add components, and to modify D-value equations with no rewriting of internal code. Adding new feed components is simplified because the component information can be added directly to XML files along with the new D-value functions; only minimal familiarity with MATLAB is required.

[ANL] Work continues on improvements to ROTOR code functionality using a MATLAB implementation that had been converted in the previous FY from the Excel version originally developed by Leonard. Recent work has focused on verifying the equations implemented in the code to accommodate changes to the contactor rotor designs enabled with additive manufacturing, as well as the reconfigurations and non-standard sizes requested for possible lab- and pilot-scale systems at INL. (C. Periera)

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 Annual Meeting: Federal Program Manager, CAM, and NTD have postponed the annual meeting due to the COVID-19 situation. MPACT PIs have indicated a strong preference for rescheduling as a face-to-face meeting to promote discussions. MPACT will need to hold this meeting no later than the end of June 2020 in order to coordinate FY-20 closing activities and prepare for FY-21 activities. If face-to-face is not possible by this time, the meeting will be scheduled as a VTC. Federal Program Manager, CAM, NTD, and Ben Cipiti continue to hold teleconferences to coordinate Milestone 2020 activities and review plans to meet MPACT Level 2 FY-20 milestone. The first draft of the overarching Milestone 2020 report has been drafted and distributed to MPACT PIs for supporting paper development. MPACT Federal Program Manager and NTD held a teleconference with the Systems Analysis and Integration NTD to discuss potential coordinated activities. MPACT Federal Program Manager and NTD participated in Material Recovery and Waste Form Development program review call to understand MRWFD activities and feed this information into the short and long-term MPACT proposed plan.

3.2 MRWFD/Advanced Nuclear Safeguards and Security Research

3.2.1 MSR Safeguards Modeling

[SNL] Current activities are being wrapped up, and this work is transitioning to the new advanced reactor safeguards area.

3.2.2 Microcalorimetry Consulting

[LANL] With a greatly accelerated delivery and testing schedule, installation of the new high-yield detector array in the SOFIA instrument has been successfully completed before LANL laboratory operations were paused due to the COVID-19 pandemic. Results show that the new detector array meets design requirements with implementation of 256 resonators with 90% yield on one microwave circuit, and greatly improved pixel yield compared with the SLEDGEHAMMER array. Energy resolution of 75 eV FWHM has been demonstrated on a subset of pixels and is expected to approach 60 eV FWHM once a minor repair can be done. With these steps completed, SOFIA will be ready for measurement campaigns designed to test uncertainty limits for the MPACT 2020 milestone.

3.3 Safeguards and Security Supporting Technologies – Echem

3.3.1 Microfluidic Sampler

[ANL] The fabrication of the new bellows actuator for priming the molten salt pump was completed and a new flexible shaft coupling was installed on the molten salt pump to reduce vibrations and make shaft alignment easier in the glovebox.

3.3.2 Bubbler for Measuring Density and Depth of Molten Salt

[INL] Two new bubblers were built from the design phase, up through early characterization in the laboratory. The fabrication cost for both bubblers was ~21.5k, including fab shop labor. Preliminary characterization shows that the larger tube diameter dip-tubes are not significantly different between each other (data at a specific depth in water are all within the uncertainty measurements). The two smaller diameter tubes do appear to be different (~4 Pa outside of uncertainty ranges). In HFEF, these tubes would likely be within the uncertainty limits of that system. The reason for the variation in the data is unknown, it may be due to a slight curvature in one of the tubes. The matter will be explored in more detail once the team is back in the laboratory. Cables were made to power cartridge heaters to explore the effect of tube heating on plugging.

3.3.3 OR Voltammetry

[INL] Collected data in HFEF twice before INL went into safe plus mode. Code in Python was developed to analyze data collected via the OR voltammetry sensor in HFEF. A code was developed to control and process data from the new potentiostat, which has been requested for purchase.

3.3.4 ER Voltammetry

[ANL] The sensor and instrumentation are at INL, awaiting resumption of normal laboratory operations. Discussion and planning have taken place with INL staff to ensure the sensor experiments will occur as soon as possible.

3.3.5 Advanced Fuel Cycle Scoping – Review Panel

[BNL] Provided input to the safeguards section of the US Fuel Disposition Concepts and Issues for Enhancing US Nuclear Industry Competitiveness in Global Markets report has been provided. Finalized the MPACT Advanced Fuel Cycle Panel Report. Discussed MPACT strategy with National Program Manager.

3.4 Safeguards and Security Milestone 2020 – Echem:

3.4.1 Advanced Integration Methods

[LANL] The work on the 2020 milestone paper is advancing. HDND results have been completed and the work toward simulating the Microcal is moving forward.

3.4.2 Safeguards Facility Models

[SNL] Some minor model updates have been completed.

3.4.3 Milestone 2020 Coordination

[SNL] Continuing to work on draft papers and coordinate papers from other laboratories.

3.4.4 Security Facility Models

[SNL] The Vulnerability Analysis continues to make progress, and a variety of scenarios are being run.

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, INL, BNL, ORNL] Held a campaign discussion on metrics that should be considered for evaluation of advanced reactor demonstration systems.

[ANL, INL, BNL, ORNL, PNNL, SNL] Campaign personnel contributed input to the SWOT (Strength, Weakness, Opportunities, and Threats) analysis for/from the Systems Analysis and Integration program area.

[ANL, INL, BNL, ORNL] The campaign has been considering what a multi-year program plan for NE-4 would contain, in anticipation of such a document being required by the DOE-NE Strategic Plan.

4.2 NUCLEAR ENERGY SYSTEM PERFORMANCE (NESP)

4.2.1 Technology Maturity & Economic Performance Potential of Microreactors

[ANL] Held a conference call on March 16, 2020, with HolosGen to share the draft assessment of technology and system readiness levels of the Holos microreactor. HolosGen agreed on the technology decomposition of Holos microreactor and identified critical technology elements (CTEs) in the draft assessment. For moving forward, ANL developed and shared with HolosGen a list of items needed for an evidence based TSRA assessment. Currently, HolosGen is reviewing the list and will provide feedback as long as there is no objection from investors.

[ANL] Developed proposed cost analysis models of gas turbines and compressors that can be used for most helium-cooled technology. This covers most of the important cost elements, but some are still to be developed and the appropriate data gathered for some systems. HolosGen committed to supporting this development. Based on discussions with HolosGen and information on other concepts, the direct overnight capital cost of the Holos will not include some functions that exist in a typical commercial nuclear power station: for instance, fuel handling machine and fresh or used fuel storage, operations and technical support, etc. This will require some revisions of assumptions in the modeling.

[ANL, BNL, INL, ORNL] Held a conference call to share the progress of TSRA and ACCERT assessment of microreactors, on March 24, 2020.

[BNL] Developed preliminary list of Technology Elements for the "INL Design-A" heat pipe reactor that will be used as one of the reference concepts considered in this activity.

[INL] INL staff met to coordinate the approach and analysis of microreactors. Developed preliminary methodology for cost estimating applied to microreactors. Also developed preliminary analyses and conducted internal review of approach.

4.2.2 Impacts of Foreign Energy Transition Policies

[ANL] Submitted the M3 report "Impacts of Foreign Energy Transition Policies as Case Studies." This report is the deliverable in fulfillment of the Level 3 milestone, M3FT- 20AN120102012 under the work package of "*FT-20AN1201020 – Nuclear Energy System Performance (NESP)-ANL*." In the report, the impacts of energy policy transitions in three countries, namely Japan, South Korea, and Germany were discussed. The motivations of energy policy transitions are different in the three countries. The Fukushima accident in 2011 damaged Japan economically and sociologically, and the energy policy of Japan changed in response to the accident. In contrast to Japan, the energy policy transitions of South Korea and Germany were motivated by political decisions. In South Korea, an antinuclear political party and its presidential candidate took political power in 2017 and the government officially adopted an "Energy Transition Roadmap" targeting nuclear phase-out and expansion of renewables. In Germany, there has been antinuclear sentiment since the 1980s, and the "Energiewende – energy transition" policy, launched in 2010 to switch its electricity supply to renewables. These three countries each have different practices for implementing their energy policy transitions. Although Japan's nuclear power industry was damaged by the level 7 nuclear accident at the Fukushima Daiichi site, the government did not plan to abandon nuclear power as a long-term energy source. South Korea's nuclear phase-out policy does not pursue a quick or immediate phasing out of nuclear plants. However, Germany has been quick to implement energy policy transitions; a "nuclear moratorium" was announced just after the Fukushima accident in 2011. In the report, the impacts of energy policy transition on national economy, nuclear industry, electricity retail price, carbon dioxide emissions, public opinion, et al., are summarized.

[PNNL] Provided review comments and recommendations for the report on the Impacts of Foreign Energy Transition Policies by ANL.

4.2.3 Factors Impacting Nuclear Energy Share

[ANL, BNL, INL, ORNL] Continued collection of information on the sustainability of nuclear energy share in the future markets from studies completed by the OECD/NEA, universities, consulting companies, etc. Through literature review, two factors (capital cost of the nuclear plant and role of nuclear energy in future high VRE penetration market) were identified as the major factors that should be further reviewed in the work.

4.2.4 Re-use of Decommissioned Nuclear Assets

[ANL, BNL, INL, ORNL] Held regular biweekly call to review information on the decommissioned nuclear assets.

[ORNL] A report section has been drafted that has collated the US decommissioned reactor sites. The work included loading their locations into a US GIS map for ease of use and identification. A brief background and status on each site were also included in the write up.

4.2.5 FCDP Development for Specific Advanced Reactors

[ORNL] The two FCDPs to be analyzed and written up have been decided as the NuScale SMR, and a representative Accident Tolerant Fuel (ATF) nuclear system. Work is now well underway to complete the analyses using SCALE that will be used in the FCDPs and associated Technology Data Sheets (TDS). New TDSs will be needed for the new fuel and reactor. In addition, as part of this task ORNL will work with SNL to test and provide feedback on the FCDP upload process and website.

4.2.6 Maintain/Update of Fuel Cycle Catalog

[SNL] Corrected problems (e.g., formatting issues, broken links) with the Public Nuclear Fuel Cycle Options Catalog.

[SNL] We continued to maintain the catalog, checking it weekly to make sure every component is working properly and correcting any problems. We also discussed several tasks that could be pursued within our scope. (1) Managing the workflow for FCDP development using the catalog, (2) allowing those developing FCDPs to upload documents using the Option Manager, (3) filling in gaps in information for components of the nuclear fuel cycle for which data packages were not provided (e.g., waste disposal), (4) revising the data entry part of the catalog to remove webparts, which will probably not be supported by SharePoint in the next upgrade, and (5) creating interactive flow diagrams automatically, based on FCDP data entered into the catalog.

4.2.7 Transition Analysis Studies and Tools Development

[ORNL] A streamlined cloud computing capability has been developed and tested for use of Cyclus. As well as the new GUI that is with the other labs for testing, a parallel activity is underway to look to utilize the NEAMS workbench for the future use and deployment of Cyclus. This provides a number of benefits including ease of use and access, standardized access for DOE-NE users, and leverages expertise in the development of GUIs for the other national programs.

[INL] Shared visualization prototypes with collaborators at ANL, ORNL. Working to finish supplemental report on analysis of partial transitions to accompany milestone report from FY-19.

[ANL] Completed first set of scoping runs of DYMOND/DAKOTA for the purposes of quality assurance and control before a full set of computationally intensive production runs are initiated. Performed an extensive review of the many features and methodologies for UQSA within DAKOTA and down-selected two to pursue for application to the fuel cycle transition scenarios: Analysis of Variables (ANOVA) and Principal Component Analysis (PCA).

[ANL, ORNL] Tested Cyclus user interface developed by ORNL with runs being submitted through cloud network. Initial impressions were positive as this approach essentially removed the installation and compiling requirements of the code on a local machine, and a simple case was simulated without errors

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

4.3.1 Improvement of ACCERT Algorithm

[ANL] The work on the microreactors identified an area where additional modification to ACCERT is required. For the HolosGen concept, functionality that represents about 25% of the direct overnight cost for a typical PWR power station is not part of the direct overnight cost of a microreactor power station. This functionality is moved off site. For instance, the fuel handling and fuel storage are not included in the Holos power station because the whole plant is fabricated in an external factory and transferred to a site. Other concepts seem similar with some SMR concepts having a reduction or increase (e.g., fuel recycle for IFR or MSR concepts) in the functionality included in the capital cost. In addition to properly accounting for any specialized factory that requires a large capital investment (making the cost sensitive to number of units produced), the functions being moved offsite need to be considered. This could include things like centralized operation facilities and centralized used fuel storage. From a cost point of view, if they have a large economy of scale or large capital investment, this will make them sensitive to the number and timing of the units deployed. A summary of the issue and ideas for addressing this are being developed.

[INL] Continued ongoing collaboration with ANL regarding algorithm enhancements. Reviewed published documentation on ACCERT as well as documents undergirding ACCERT.

4.3.2 Daily Market Analysis of Load Following and Storage Impacts

[ANL] A detailed plan for this analysis was developed and discussed with campaign management. An ALEAF model of ERCOT in 2019 was completed and showed reasonable agreement with historical data, which confirms the viability of the model used for our analyses. This model was used to assess the impact of nuclear unit shutdown for fuel reloading to confirm that modeling these outages leads to noticeable impact on the revenues of the nuclear unit and on the overall electricity price.

[ANL, BNL, INL, PNNL] Organized meeting on March 19, 2020, where we discussed the impact of the time-modeling strategy in different capacity expansion codes on estimated nuclear deployment. In particular, we discussed how to leverage the results from analyses performed in A2.1 to help quantify the impacts time-slices have on capacity expansion results.

[BNL] Participated in monthly telecom led by ANL.

4.3.3 Cost Basis Report Enhancements

[ANL] Williams (ANL-Contractor) is continuing his work on updating and revising fuel fabrication cost modules in the Cost Basis Report.

[INL] Continued to collaborate with ANL on plans and implementation of updates to the CBR. Drafted outline for annual report on Cost Basis Activities and circulated for discussion.

4.3.4 Regional and Global Analysis

[PNNL]. Completed GCAM modeling simulations (updated) of long-term nuclear energy scenarios for supporting draft paper on assessing the role and value of nuclear energy for deep decarbonization. Currently in the process of preparing a draft paper suitable for journal publication.

[PNNL] Participated in Daily Market Analysis project to assess the capabilities of electric power sector models and their ability to address associated impacts of intermittent or variable energy generation.

[PNNL] Contributed to the OECD/NEA ARFEM expert group to prepare final draft of report on the role of nuclear energy in future energy markets. Provided review, comments, and recommendations on draft report.

4.3.5 Lessons-Learned from LWR Deployment History

[BNL] Participated in biweekly conference calls with INL to discuss progress.

[BNL] Provided additional documents to the project SharePoint library.

[BNL] Working on providing input to and reviewing draft of final report.

[INL] Continued to lead team members on this task with biweekly conference calls to coordinate the effort. Drafted text for assigned sections of the report and created additional visuals for present findings.

4.3.6 Adaptation of OR-SAGE for NES Analysis

[ORNL] The team has worked with ORNL's IT department to create a virtual machine on an ORNL enterprise server to allow us to publish the OR-SAGE tool as an external-facing platform for other users.

[ORNL] A number of tasks have been completed as part of the OR-SAGE back-end design and development:

- Implemented login access for factor rating to allow specific users to provide rank information for data layers impacting suitability.
- Implemented a sign-up page to allow users to create accounts if they do not have an existing account.
- Created the interface to allow user input for ranking each factor.

- The web application is now implemented using Java Server Pages, and connection to the database for the login access, account registration/signup is implemented using servlet and JDBC connection between the front page and PostgreSQL database.

In addition, the team has had discussions with EIA staff about getting regional-level nuclear energy generation projections.

[ORNL] Work has continued to support the University of Michigan (UM) to determine how the OR-SAGE development work might dove-tail with an ARPA-E project proposed by UM to support policy decisions that impact reactor projects and reactor siting. Following the meeting, a work proposal was prepared detailing how ORNL could support this effort. In addition, a separate inquiry has been received from the University of Illinois at Urbana-Champaign (UIUC) on how OR-SAGE may be able to support the UIUC desire to host a microreactor.

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:

- In early March, HFEF received three IRT test pieces irradiated in ATR. Initial non-destructive analysis of IRT capsules was underway.
- The fourth 4-kg electrorefining test with irradiated LWR fuel was nearing completion.
- Preparations for the fifth 4-kg oxide reduction test were ongoing.
- Electrodes were removed and systems remain in hot standby.

Status of Critical Gap activities:

- An investigation of improved electrode designs (porous shrouds, planar electrodes) was underway. System was placed in hot standby.
- Preparations for production of OR salt waste forms at HFEF were ongoing.

The U.S. Executive Agent signed the 2020-21 Nuclear Technology Transfer sheets for JFCS.

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

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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 2020 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 2020 was midnight, Sunday, March 15. Due to student disruptions associated with COVID-19, the deadline was extended to Sunday, March 22.

Each applicant submitted an application and a recently published paper or conference proceeding. The student is required to be the first author or the primary student author.

Fifty-eight eligible applications were received from 25 universities, numbers that have remained fairly constant between competitions.

Eligible applications were received in the following categories:

Category	Number of Applications
Advanced Fuels	10
Advanced Reactor Systems	14
Energy Policy	5
Material Protection	6
Material Recovery	6
Nuclear Science and Engineering	12
Used Fuel Disposition	5

All applications are eligible for the Open Competition. Twenty-four applications are eligible for the Open Competition only. Twenty-eight applications are also eligible for the Competition for Students who Attend Universities with Less than $600 Million in 2018 Science and Engineering R&D Expenditures. Seven applications are also eligible for the Undergraduate Competition.

Six of this year's applicants have won an award in a previous year and are eligible only for an award at a higher level than the award which they won previously. Two applicants submitted more than one eligible application.

Applications were received from the following universities:

Air Force Institute of Technology
Boise State University (2)
Colorado School of Mines
Florida International University
Georgia Institute of Technology (3)
Massachusetts Institute of Technology (2)
North Carolina State University (2)
Northwestern University (2)
Penn State University
Purdue University (2)
Rensselaer Polytechnic Institute (2)

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Texas A&M University (3)
University of California at Santa Barbara (2)
University of Iowa
University of Florida (2)
University of Idaho (2)
University of Michigan (11)
University of Nevada at Las Vegas (3)
University of Nevada at Reno
University of Pittsburgh
University of Tennessee at Knoxville (7)
University of Utah (2)
Vanderbilt University
Virginia Commonwealth University (2)
Washington State University

University Research Alliance is compiling the applications packages for distribution to three reviewers.

University Research Alliance has been removing email addresses for rejected announcement emails and removing addresses of people who have asked to be unsubscribed from the list. This process will continue with each announcement.

University Research Alliance is continuing preparations for the 2020 Innovators' Forum, scheduled for May 26-28 in Nashville, TN.

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