INL/EXT-19-56823

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

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Idaho National Laboratory

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**Idaho National Laboratory**
**Idaho Falls, Idaho 83415**


**http://www.inl.gov**


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

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## 1. ADVANCED FUELS CAMPAIGN

## 1.1 Advanced LWR Fuels

### 1.1.1 LWR Fuels

**[INL]** The hydrogen system subcontractor, Thermal Technologies, is finalizing fabrication efforts with an expected delivery to INL in early November. (M. Cole)

**[ORNL]** UO2 doping was carried out using Cr2O3 up to 2000 wppm concentrations. The sintered samples held at 1700 °C for 10 h under flowing Ar-4%H2 gas environment showed that UO2 grain growth can only be achieved up to a nominal maximum average value of 20 mm. It was also shown that the UO2 grain growth was maximum at approximately 1000 wppm Cr2O3 concentration. Sol-gel synthesized 1000 ppm TiO2-doped UO2 microspheres were also sintered at 1700 °C in Ar-4%H2 atmosphere. Samples sintered with 2 – 10 h holding times produced a UO2 microstructure with bimodal grain distributions. Even though the presence of bimodal grain distribution was mostly diminished after sintering using longer holding times (16 and 24 h), some samples showed isolated areas with smaller grains. While nominally uniform grain size distribution was observed in the samples fabricated grinding UO2-TiO2 (1000 ppm) microspheres, sintering for 10 and 24 h also resulted in average UO2 grain sizes close to 30 mm and 50 mm, respectively. The sintered pellet samples had ≥ 95 %TD. For example, the densities of the 10 and 24 h samples were 10.5 (95 %TD) and 10.6 g/cm3 (96 %TD), respectively. (C. Silva, R. Hunt, A. Nelson)

**[ORNL]** Postirradiation examination of the first irradiated MiniFuel target (MF-01) continued. This irradiation contained several uranium nitride kernel variants that could be deployed in advanced coated particle fuel concepts. The SiC thermometry recovered from the first 6 MiniFuel subcapsules was analyzed. The average irradiation temperature measured from the thermometry was about 400°C which is slightly lower than the expected irradiation temperature range of 425 to 480°C. Optical microscopy was also performed on kernels from MF-01. This is the first microscopy of fuel irradiated in a MiniFuel capsule and demonstrates that the fuel kernels can be retrieved from the sub-capsule for further advanced exams. The observed microstructure of the U(C,N) kernels is largely similar to the as fabricated microstructure. This was expected with the low burnup that these kernels experienced of less than 10 MWd/kgU. An example of the optical microscopy from a UC0.2N0.8 kernel that was in the MF-01 221 sub-capsule is shown in Figure 1. The most notable feature in the microscopy of the U(C,N) kernels is a shallow rind that appears to have formed on the outer surface of some of the kernels. This may be an artifact from fabrication such as an oxide layer. This feature will be examined further in future electron microscopy exams. (J. Harp, A. Le Coq)

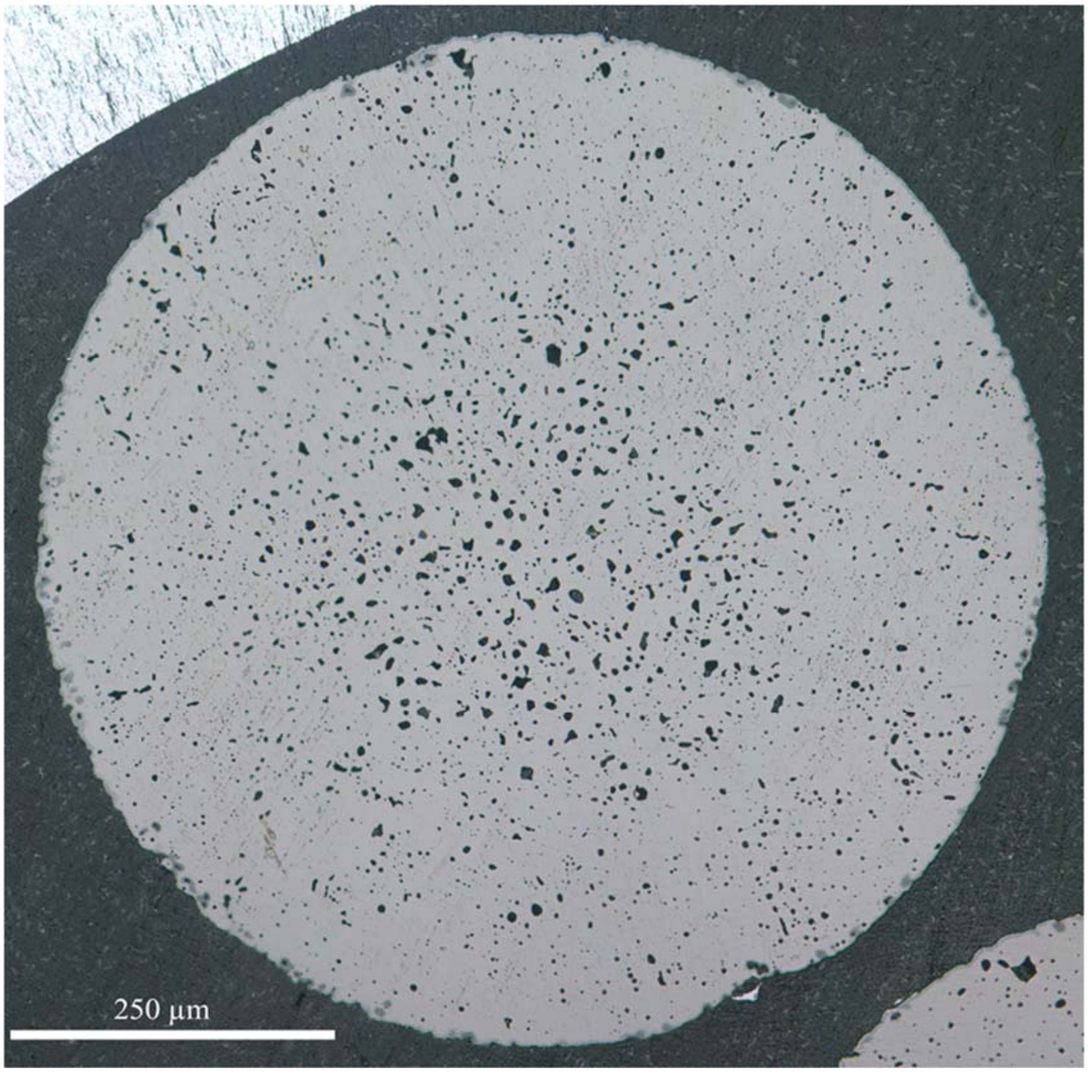

Figure 1 Optical microscopy of a $U(C_{0.2}N_{0.8})$ kernel irradiated in the first MiniFuel target. A portion of a second kernel is shown in the bottom right portion of this image.

### 1.1.2 LWR Core Materials

**[INL]** Irradiation of ATF-2 in ATR cycle 166B was completed in October reaching ~178 effective full power days. Reconfiguration of fuel pins for ATF-2B1 was also completed. The ATF-2B1 configuration includes boiling water reactor (BWR) type rodlets in Tiers 3 and 4 and a fully fueled test train with pressurized water reactor type rodlets in Tiers 1, 2, and 5 in ATR Loop 2A at more prototypical pressure and temperature. During reconfiguration, hardware problems associated with the test train and experiment handling tools have slightly delayed experiment insertion. The project team is currently working to resolve those issues and still meet the cycle 166B insertion target early November. (G. Hoggard)

Preliminary design and analysis efforts to support new ATF-1 scope for Framatome continue to progress. Fabrication of most capsule components and gauges has completed. Preliminary enrichments for the design specifications of the fuel rodlet have now been validated by Framatome. Conceptualization of a new ATF material test called Cladding Creep is on-going. Kick-off for the FY2020 design efforts has completed. The 166B cycle outage is nearly complete. Preparations for the 166B cycle are complete and the experiment has been reinserted in the ATR. (C. Murdock)

A report summarizing the non-destructive examinations conducted so far on three ATF-1 rodlets has been written and issued. The report contains results of visual examination, profilometry, gamma spectrometry and neutron radiography of one U3Si2 fuel rodlet with Zirlo cladding and two UN- U3Si2 fuel rodlets with Zirlo cladding. Westinghouse was the concept-lead of all the three ATF-1 rodlets. (F. Cappia)

### 1.1.3 LWR Fuel Safety Testing

#### *1.1.3.1 LWR Modeling & Analysis*

**[ORNL]** Fuels performance modeling activities in October focused on completion of a manuscript describing the effect of BWR control blade position on the deformation of silicon carbide channel boxes, which has been submitted to Nuclear Engineering and Design (based on the work presented in M2FT-19OR020205031), in addition to completing the BISON fuel performance modeling assessment of uranium silicide fuel under water ingress accident conditions. This effort on uranium silicide will be documented in the milestone to be submitted in November. (B. Wirth)

**[BNL]** An input model is being assembled to conduct a TRACE-Dakota uncertainty analysis for a reactivity-initiated accident (RIA). In the past, an RIA was simulated by running a TRACE restart case with the reactivity insertion defined in a Power Component. This was found to not be compatible with the setup of executing the parametric cases for the uncertainty analysis. Since initial reactor power was one of the sensitivity parameters, there is no known method to pass the parametric value as an input if the Power Component had to be redefined in a restart case. An alternate means of defining the reactivity insertion was developed. This was done by using control variables to provide reactivity to the Power Component, thus avoiding the need to redefine the Power Component in a restart case. (L.-Y. Cheng)

**[BNL]** An effort has been initiated to perform analyses with FRAPCON based on Serpent Monte Carlo results for the radial power distributions as a function of burnup in full- and half-diameter UO2 pellets in an ATR irradiation capsule. The FRAPCON analyses will provide fuel performance related information including fuel temperature distributions, fission gas release, etc. (L.-Y. Cheng, A. Cuadra, M. Todosow)

## 1.2 Advanced Reactor Fuels

### 1.2.1 AR Fuels

**[INL]** The FAST experiment series includes several experiments utilizing a zirconium lined cladding tube. The cladding tubes were produced by drawing down excess EBR-II cladding tubes to the FAST dimensions. During the drawing process, a zirconium rod was inserted into the tubing and co-drawn to final size. Variants of the process included when the zirconium rod was inserted into the cladding tube and heat treatments. A sample of each variant was taken and examined for intimate contact between the cladding and zirconium. Figure 2 shows typical examples for each sample. After the best variant is identified, the zirconium rod will be drilled into a tube and used for the FAST irradiation test. (R. Fielding)

(a) (b)

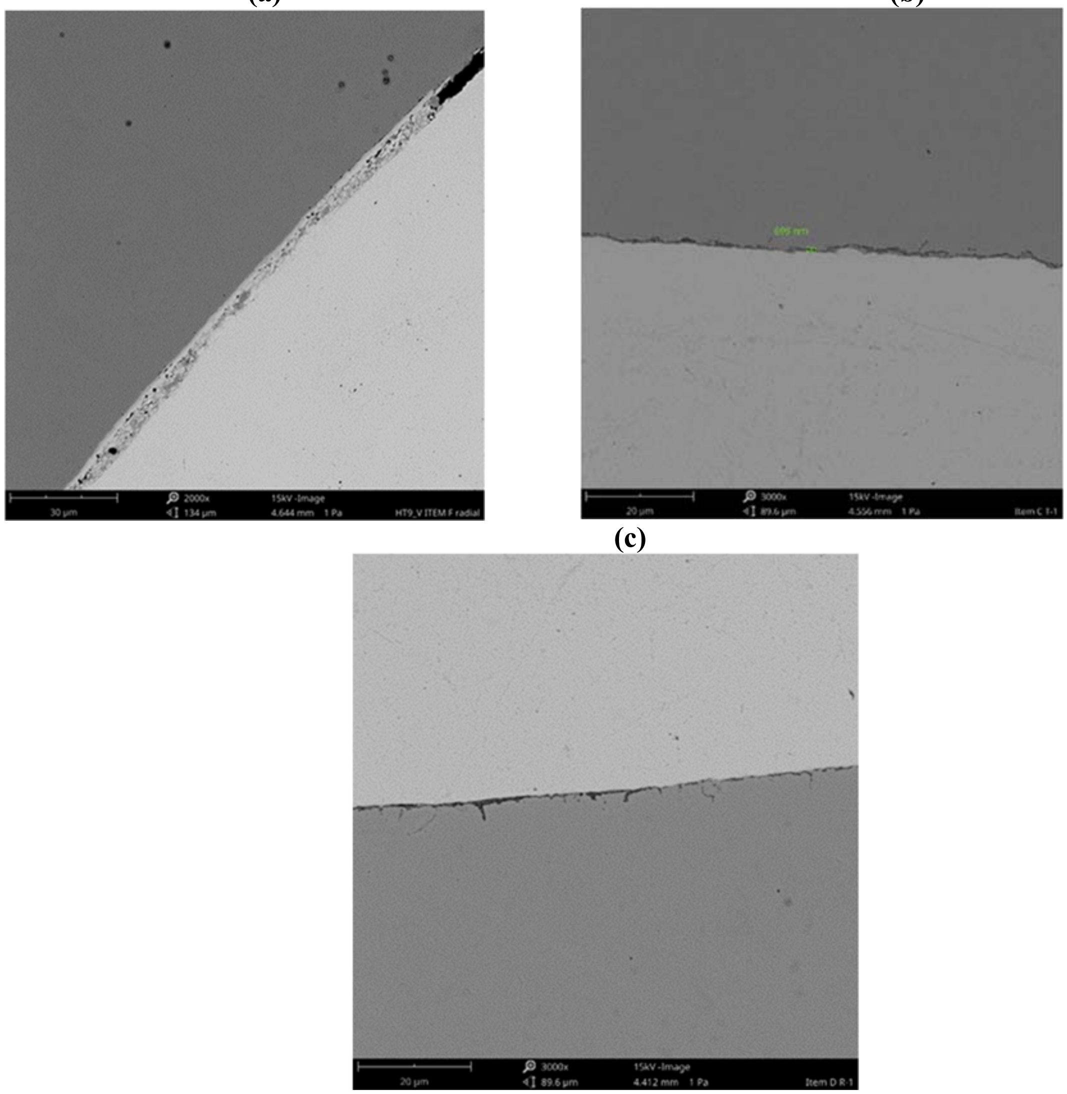


Figure 2 (a) sample F normalized and tempered with Zr in place; (b) sample C tempered with Zr in place; and (c) sample D - HT-9 and Zr co-drawn with no additional heat treatments.

A publication titled, “In search of θ-(Pu-Zr) in binary Pu-Zr:  Thermal and Microstructural Analyses of Pu-30Zr Alloy,” was accepted for publication in the Journal of Nuclear Materials. (J. Giglio)

**[ORNL]** Uranium Zirconium alloy samples from INL were received at ORNL.  These samples are in controlled storage until an optimum thickness can be estimated from modeling and simulation of U-Zr alloys in the MiniFuel irradiation vehicle.  An irradiation test matrix for the U-Zr MiniFuel irradiation was also drafted and discussed with AFC staff to establish the initial goals of the U-Zr MiniFuel irradiation and help guide the design. (J. Harp)

### 1.2.2 AR Core Materials

**[LANL]** The latest results of shear punch testing on irradiated HT-9 and 14YWT alloys were presented by Ben Eftink at the International Conference of Fusion Reactor Materials in San Diego, CA. (B. Eftink)

**[PNNL]** All three of the 9Cr alloys to be fabricated for milestone M4FT-19PN020302022, titled, “Conduct 9Cr Alloys Development and Testing at PNNL and Write Report,” have been completed.

Initial microstructure exams have started that will include documenting grain structure, grain boundary carbides, and hardness of each of the alloys. (M. Toloczko)

**[ORNL]** An oral presentation titled, "Effect of Neutron Irradiation on the Microstructure of the ODS 14YWT Ferritic Alloy," was given at the Materials in Nuclear Energy Systems (MiNES) 2019 conference in Baltimore, MD on October 6-10, 2019. The significant results covered in this presentation demonstrated that the microstructure of 14YWT was stable in showing no changes in the nano-size oxide particles and no formation of cavities or dislocation loops. New evidence shows that 14YWT is susceptible to formation of Cr-rich alpha prime particles below irradiation temperatures of ~440ºC. There were many questions and follow-up discussions regarding these results following the presentation. (D. Hoelzer)

The preparation of 6 SS-3 type tensile specimens with extended grip sections of 14YWT (Pm1 heat) that were tested in the forced convection sodium (Na) loop at Argonne National Laboratory was initiated for both tensile tests and microstructure analysis. The Na tests were conducted in three experiments starting in 2017. Each of the three experiments included two SS-3 tensile specimens that were exposed to the flowing Na. The final exposure conditions of the three experiments were: (1) 1,820 h at 650ºC, (2) 2,304 h at 600ºC and (3) 5,345 h at 550ºC. After the Na loop tests, the specimens were shipped to LANL and cleaned with alcohol and water to remove surface residues. The 6 Na loop tested specimens and 2 control SS-3 modified tensile specimens of 14YWT were shipped to ORNL in early 2019. The significance of this work is to understand the corrosion behavior of 14YWT exposed to molten Na in test environment and conditions that are representative to Sodium Fast Reactors. (D. Hoelzer)

**[PNNL]** As part of the program to advance the technology associated with fabricating tubing from difficult-to-fabricate materials, the PNNL rolling mill has been modified so that it can perform pilgering of thick-wall tubes. This capability to pilger thick-wall tubes into finished thin-wall tubing establishes a unique R&D capability within the DOE complex.

The plan for this fiscal year is to build upon the two pilgering runs on 14YWT completed during FY-19 by extending the length of the pilgered tube. Current plans are to pilger both a 24 inch and a 36-inch thin-wall tube of 14YWT, and possibly a tube of FeCrAl. This will require a longer actuator and longer mandrels. The longer actuator has been procured and installed on the rolling mill. An initial run with the longer actuator has been performed by a sister program in PNNL. The intent in this sister program is to roll a foil and not to pilger at tube. Nonetheless, the longer actuator successfully rolled a foil out to 36 inches which was the measure of success here, which is a positive indicator for our pilgering program. (R. Omberg)

### 1.2.3 AR Irradiation Testing & PIE Techniques

**[INL]** The FAST-1 group of experiments has concluded the final design phase. The final enrichments, temperature and structural analyses are complete and tech checked. The final design review kickoff meeting is scheduled for the end of October. Fabrication is nearly complete for the outer capsule components. The inner capsule components have started and are making progress. Kickoff meetings for the FAST-2, 4F/4G, and Booster I-position studies as FY2020 efforts has completed. The 166A irradiation cycle completed and preparations for the 166B irradiation cycle are complete with insertion in the reactor and issuance of the cycle-specific physics analysis now issued. Programmatic analysis will be completed after the reactor startup due to the short outage. (C. Murdock)

FIB lamellas preparation and TEM examination has been performed on a sample from EBR-II transmutation fuel pin X501-G591, U-20.2Pu-9.1Zr-1.2Am-1.3Np fuel composition that has been irradiated to 6.1% FIMA. Scanning transmission electron microscopy with energy dispersive X-ray spectroscopy (STEM-EDS) and diffraction patterns were used to study the microstructure of the different phases and Am based precipitates. Figure 3 shows a SEM macrograph of the X501 sample (left); I, II, III are SEM images showing the TEM lift-out locations from the red highlighted region (fuel center) in the macrograph. In the second line: (a) STEM BF image of the lamella and (b) to (d) are elemental mapping of Zr, U, and Pu, respectively.

Diffraction patterns and nanoscale features are being interpreted and related to the overall fuel performance of the fuel pin. (L. Capriotti)

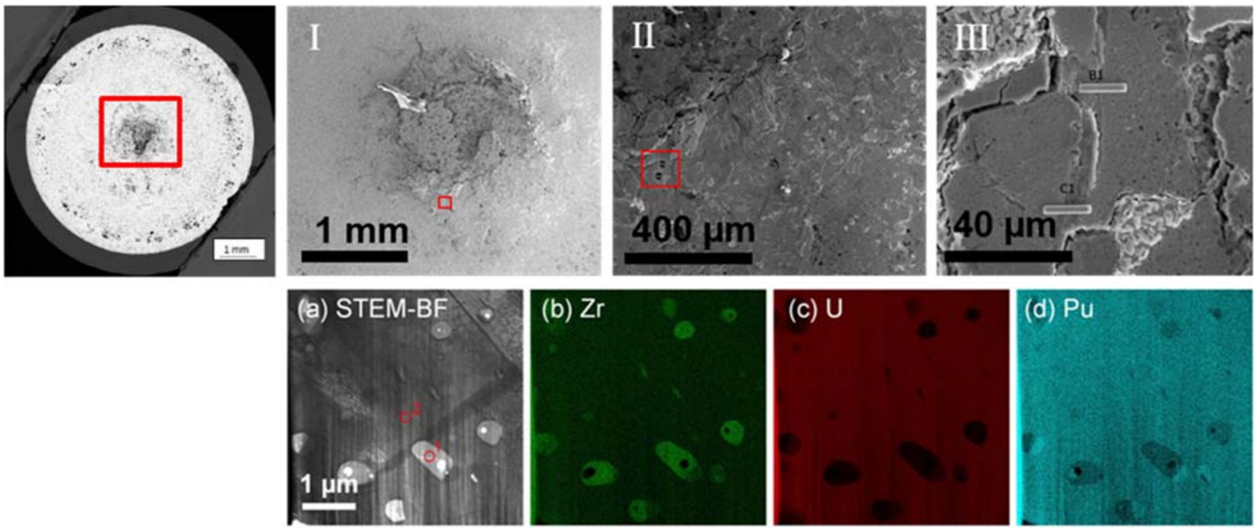


Figure 3 SEM macrograph of the X501 sample (left); I, II, III are SEM images showing the TEM lift-out locations from the red highlighted region (fuel center) from the macrograph, and (a) STEM BF image of the lamella and (b) to (d), elemental mapping of Zr, U and PU.

Engineers are in the process of developing a software interface that will integrate with existing controls on the hot cell furnace for fuel pin testing. (M. Cole)

### 1.2.4 AR Fuel Safety Testing

**[ANL]** Competitive micro thermal neutron reactor concepts that feature advantageous compactness, efficiency and inherent safety require adoption of advanced neutron moderators that operate at elevated temperatures. In this project, different moderator options for micro-reactors are explored so as to guide future micro-reactor design and performance analysis. In October, literature review was performed to study available condensed forms of materials that contain high density of moderator elements (e.g. hydrogen, beryllium, carbon, etc.). Both solid and liquid states of moderators were considered. Physical and chemical properties of these potential moderator materials were also collected for future performance analysis under this project. (T. Kim)

## 1.3 Capability Development

### 1.3.1 CX TREAT Testing Infrastructure

**[INL]** A new laser for excitation has been ordered. (R. Schley)

## 1.3.2 CX Halden Gap Activities

### *1.3.2.1 TREAT*

**[INL]** Evaluation of different LOCA testing vehicles is in process. RELAP models have been constructed and various operational scenarios are being run in order to compare results and determine which design will best support LOCA testing in the near term. (D. Dempsey)

The project team was selected, and work initiated for the use of pre-irradiated fuel in a MARCH-SERTTA capsule. Work commenced on a modified rodlet holder to enable loading of a fuel rodlet with manipulators in the HFEF hot cell. In addition, other design modifications for remote loading and unloading have been initiated. (L. Emerson)

FY-20 efforts were kicked off. Support is ongoing for concurrent testing at TREAT for experiments. (T. Pavey)

ATF-SETH A-E capsule disassembly, visual inspection, cutting material for mounts, and mounting is completed. Efforts are underway to polish samples for optical microscopy. (M. Bybee)

FY-20 efforts commenced on hydriding cladding at IRC. (T. Pavey)

Efforts to develop high burnup rod defueling capability are underway. A device is being designed for the collection of the fuel after sectioning. The expected time frame is the end of December.

Efforts continue to develop a capability to machine tensile test specimens. A non-rad sample has been milled to explore the milling capability. A four-axis mill is installed in the cold lab of HFEF to develop milling on non rad sample. Preliminary design of the ring tension fixtures has been done. Fixtures will be updated after discussions with HFEF engineers. (M. Bybee)

Support was provided for operation of the hodoscope during experiments. Six experiments were run in October. Preparation of 96 detectors for installation at TREAT is underway. (T. Pavey)

The conceptual design process is underway. The determination was made that this fiscal year will be focused on a test vehicle that can accommodate test rodlets up to 16 inches in length. This enables the design team to focus on a single design. (D. Dempsey)

Conceptual design is on track and progressing as expected. (T. Smuin)

Assembly for CINDI is on track and progressing as expected (T. Smuin)

Initial work has begun to resurrect old procedures on Sodium handling to start discussions with HFEF personnel on past sodium work and the path forward for THOR PIE.

A meeting held with all HFEF pertinent personnel to discuss the feasibility of recovering various fuel types from RSWF. HFEF indicated that they would start the process of putting a system in place so that various programs can recover fuel as needed for ongoing experiments (M. Bybee)

Efforts are underway to load and seal the ATF-2 rodlet. Discussions were held with engineering personnel and changes were suggested to for the rodlet holder in the MARCH-SERTTA capsule to make loading the rod easier. Engineering has begun mapping out the process flow diagram for the procedure so drafting can begin.

A process flow diagram was developed for assembly and disassembly of MARCH SERTTA to support drafting of the procedure, and to help identify all of the tools that need to be designed and built to do the work. Design of the tooling/fixtures needed to perform the work is underway. The need for supplementary shielding in the MARCH SERTTA device due to the hands-on work that will be performed in the cask tunnel on the "buster flange" was identified. The design is being reworked to accommodate the supplementary shielding. We are also working with TREAT ops to build a "control system" similar to the one used to operate the experiment rig during the irradiation that we will use to test instrumentation, etc. that the assembled rig is good to go before shipping to TREAT. (M. Bybee)

The F&OR documents for re-fabrication and instrumentation techniques are currently being reviewed, which will feed the design activities. A draft performance specification for a new circumferential welding system has been developed and sent to companies as a request for information. A contract will be negotiated and the company will then proceed to develop detailed design documentation and manufacture the necessary equipment. (M. Cole)

Design work continues for the closure plate and In-Pile Tubes. Flow testing at OSU has begun. (T. Maddock)

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

# 2. MATERIAL RECOVERY AND WASTE FORMS DEVELOPMENT

## 2.1 International Collaborations

Gregg Lumetta traveled to Forschungszentrum–Jülich in Germany to participate in a flowsheet test of the ALSEP solvent extraction system for separating minor actinides from dissolved nuclear fuel. This test used a simulated high-level waste raffinate from a PUREX type process that had been spiked with americium and curium isotopes. Preliminary data collected during the course of the experiment were promising, indicating that the separation chemistry behaved as expected. (G. Lumetta)

## 2.2 Aqueous Processing

**[ONRL]** The advanced intermediate (compound **A**) has been synthesized in two steps. The C-H bonds at *para* position in pyridines will now be borylated using Ir as a catalyst and 3,4,7,8-tetramethylphenanthroline (tmphen) as a dative ligand.

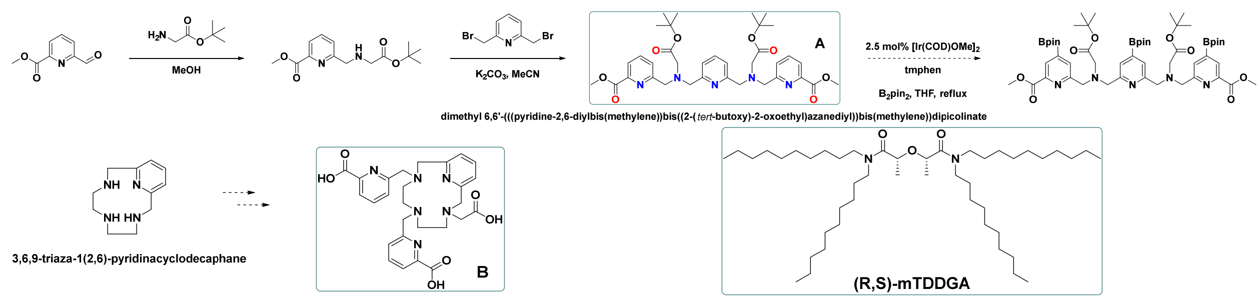


Figure 4 Upon arrival of the starting materials (expected in 1-2 weeks), the synthesis of compound **B** and (*R*,*S*)-mTDDGA will be initiated.

DFT calculations for four different polyaminocarboxylic acids are being executed to include complexation with $Nd^{3+}$, in addition to complexes with $Am^{3+}$ and $Eu^{3+}$. This will give a better comparison between $Am^{3+}$ and $Nd^{3+}$ having more similar ionic radii and hydration free energies. (S. Jansone-Popova)

## 2.3 Domestic Electrochemical Processing

### 2.3.1 Molten Salt Waste Forms

**[ANL]** Long-term tests initiated in FY19 with two iron phosphate materials were sampled and stored. These will be analyzed with samples taken later to determine the effect of solution feed-back on the dissolution rates of iron phosphate waste forms. Short-term tests indicated negligible attenuation due to either solution affinity or surface layer barrier effects. Plans for materials to be made and tested during FY20 were discussed with colleagues at PNNL and INL. The results of on-going tests will provide insights into the tests that will be run with the new materials. (W. Ebert)

**[PNNL]** First-of-a-kind experiments were conducted at PNNL to evaluate the phosphate-salt processing method (dehalogenation) with a pure lanthanide chloride stream. This process resulted in a mixture of RE-P-O crystalline phases that were then successfully vitrified at high temperatures after the addition of an Fe-P-O glass (i.e., $P_6Fe_4O_{21}$) into a glassy waste form. This demonstration opens the door for additional experimentation through the implementation of this method for other salt streams where the eutectic salt has been removed; these waste form products have notably higher fission product loadings than a waste form produced from a salt where the eutectic salt cations (i.e., Li, K) and Na (i.e., bond) are left in the starting salt. (B. Riley)

### 2.3.2 Mechanisms and Material Behavior

**[ANL]** Long-term tests with reference borosilicate glasses initiated in FY19 were sampled and analyzed. These tests are being used to measure the effect of pH on the triggering of Stage 3 behavior in glasses representing waste glasses made at the DWPF. An electrochemical test method developed to study the importance of galvanic coupling between AgI particles in iodide waste forms made with HIPed mordenite and the steel HIP can at pH 4, pH 7, and pH 10 were completed. The results are still to be analyzed, but they appear to indicate corrosion of the steel HIP can protects the AgI, and the AgI inhibits passivation of the stainless steel. Also, preparing HIP waste forms at high temperatures (e.g., 900 °C) caused sensitization of the steel without benefiting the durability of the mordenite encapsulating the AgI. Tests conducted during FY20 will quantify the effect of galvanic coupling on the waste form durability and be included in the degradation model that is being developed. (W. Ebert)

**[PNNL]** A paper titled, "Corrosion Test Method Evaluation for Iodine Waste Forms," was presented at MS&T 2019 in Portland Oregon. Authors: Amanda Lawter; Matthew R. Asmussen; Jeff Bonnett; Joelle Reiser; Nancy Avalos; Brian Riley. (M. Asmussen)

### 2.3.3 Glass Ceramics Waste Forms

**[SRNL]** The milestone titled, "Draft report on the impact of microstructure on corrosion of melt processed ceramics," is complete and the draft report was issued.

The final report detailing microstructure and corrosion of melt processed ceramics is awaiting surface area analysis of samples. Additional characterization of surfaces/surface area is ongoing to aid interpretation of the results. (P. Smith)

## 2.4 Electrochemical/Molten Salt Processing

**[ANL]** Insights from electrochemical tests completed during FY19 are being used to develop a test plan. (W. Ebert)

Components for demonstrating co-deposition of uranium and rare earth elements (as surrogates for TRU) in an engineering-scale cell have been designed and are being fabricated. The cell is being prepared for tests and some components are being restored or replaced after the developmental studies completed during FY19. (W. Ebert)

## 2.5 Sigma Team - Off-Gas

**[INL]** The activity titled, "Support assessment of the off-gas system requirements/conceptual design for pyroprocessing of metallic UNF," was initiated. The first phase of this activity is to support ORNL on an ORNL Level 4 milestone due January 31, 2020, to "Identify pyroprocessing off-gas characteristics, isotopes of concern and gaseous concentrations." (N. Soelberg)

**[PNNL]** A keynote lecture titled, "Overview of waste forms for diverse waste streams: synthesis and characterization," and an invited talk titled, "Tailoring properties of silver-functionalized silica aerogel," were given at the 43rd Symposium on the Scientific Basis for Nuclear Waste Management which was held October 21-24, 2019 at IAEA in Vienna, Austria. (J. Matyas)

PNNL, in collaboration with Massachusetts Institute of Technology, evaluated a series of ultra-microporous MOFs, SIFSIX-M (M= Zn, Cu, Ni, Co or Fe) for their potential in $^{85}Kr$ separation. All materials were systematically studied for gamma irradiation stability, which revealed that the metal center in these isostructural frameworks plays a crucial role in their radiation resistance. This is reported in a paper titled, "Radiation-Resistant Metal-Organic Framework for Efficient Separation of Krypton Fission Gas from Spent Nuclear Fuel." (P. Thallapally)

**[ORNL]** A thin bed test was completed that characterized the adsorption of CH3I by AgZ at 150℃ with a 4.3 m/min gas velocity. The CH3I concentration was 33 ppm. The sorbent was observed to gain 97 mg/g AgZ. The iodine loading will be confirmed by neutron activation analysis and will be compared to similar tests that include NOX and water in the feed stream. (R. Jubin)

The literature evaluation for the task titled, "Complete an evaluation of Ru trapping methods for use under DOG conditions and complete a series of scoping tests to demonstrate the viability of 2-3 selected methods," is ongoing. The chemistry of ruthenium in the DOG system is very complex. Ruthenium tetroxide tends to plate on metal surfaces, but in the presence of nitrogen oxides and nitric acid vapors it can be converted to nitrosyl ruthenium nitrates. In that form, it can be re-oxidized to volatile RuO4, once again becoming mobile. Tests to evaluate the stability of plated RuO2 in such an environment is indicated. The draft is about 15% complete. (R. Jubin)

The milestone titled, "Evaluate the iodine retention of long-chain organic iodides on both AgZ and AgAerogel over the range of expected concentrations in both the DOG and VOG systems and issue joint ORNL / INL report," is complete, and the fully approved report was issued on 10/31/2019. A summary of the report is included below:

- ORNL and INL have begun the execution of a multi-year joint test plan intended to provide a better understanding of organic iodide adsorption from VOG conditions. In this fiscal year, ORNL has conducted thin bed testing on the adsorption of CH3I and C4H9I by AgZ and has conducted deep bed testing on the adsorption of C4H9I by AgZ. INL has conducted extended duration deep bed testing on the adsorption of C4H9I and CH3I by AgZ and AgAerogel. This testing provides data on the adsorption rate as a function of hydrocarbon chain length and concentration. Limited data on the saturation concentration of long-chain iodides on silver-based sorbents has been obtained by both ORNL and INL, and some differences were observed between the two laboratories and across different organic iodine species. Results indicate that once the iodine loading is normalized to Ag content, both AgZ and AgAerogel have about the same capacity. DFs over a fixed bed length have been obtained by INL for elemental iodide, CH3I, and C4H9I. DFs generally trend high enough to meet or exceed minimum values expected to be needed to meet regulatory limits. These results provide proof-of-concept confirmation that engineered sorbent bed designs have potential to meet 129I air emission regulatory limits. Both ORNL and INL continue to execute the multi-year joint test plan in close collaboration. Continued success is expected as additional data is obtained and key questions regarding organic iodide by silver-based sorbents are answered. It is expected that completion of the test plan will result in the ability to provide reliable engineering designs for the removal of iodine from VOG streams. (R. Jubin)

## 2.6 Melter Demonstration

**[INL]** INL's IEDF bay W1 has been cleared in preparation for using the area for the demonstration unit. The design team has been assembled. Design/build specifications for long lead sub-systems have been completed including the canister, the off-gas system, the feed system, and the furnace systems. Procurement of the canister, off-gas and feed systems is complete.(E. Nef)

**[PNNL]** PNNL completed design of the Zircex/HURD Furnace. Design of all canister lid components was completed and fabrication and machining of components was begun. The specification titled, "Furnace Design and Fabrication for Intermediate Scale Vitrification System," was issued ( PNNL-SA-

148606). A vendor was identified to provide melter off-gas sampling and analysis (supports M3FT-20PN030202023 and M3FT-20PN03020202). (B. Riley)

## 2.7 Material Recovery Pilot Plant

**[INL]** The Material Recovery Pilot Plant became operational for the first time this month. In the first two runs, HCl gas was introduced into the pilot plant to test the scrubber systems ability to adequality remove the HCl from the off-gas prior to being released from the building. These tests were successful and allowed testing to proceed with zirconium samples. Two tests with zirconium were completed in October. These tests were critical for understanding how the pilot plant operates and responds to the various reaction taking place throughout the system. Future work can commence with larger pieces of zirconium. (M. Warner)

**[ORNL]** To optimize the hydrochlorination processing conditions, a series of initial parametric studies identified in consultation with the Idaho National Laboratory were completed. Based on these results, next tests will be focused on using 60 mesh silica as the fluidizing media and extending the hydrochlorination run to a higher degree of completion. In place of measuring and controlling the temperature of the coupon samples, the temperature of the bed in proximity of the sample will be measured and controlled. Equipment modifications for these new series were completed and the new tests will be run shortly. An experimental setup is being designed for the U3O8 Elutriation and components are being procured.(R. Jubin)

## 2.8 Polishing and Solidification (Extraction, Conversion, Downblending)

**[INL]** The lab scale team is scheduled to start the dissolution process on an EBR II fuel regulus on Nov 12th in CFA-625. Separation and precipitation will follow the dissolution to produce HALEU. The team and crafts have worked long hours to complete the enclosure fabrication, install process equipment and complete final sign-offs (Figure 5). (R. Watson)

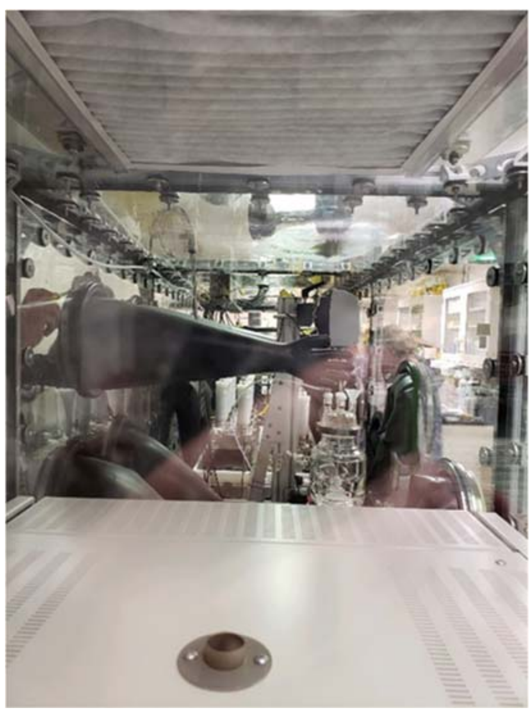

Figure 5 Inside of the uranium polishing lab scale enclosure.

Pilot scale Functional and Operational Requirements (level 4 milestone) were drafted. The F&OR will be used in addition to the scope of work to confirm the details of the demonstration to the engineering contractor, MPR. Technical discussions are ongoing to eliminate process uncertainties and freeze the engineering design scope. (R. Watson)

**[ANL]** Work has continued on zero-point and hold up testing for 2-cm and 3-cm rotors with particular focus given to the O/A ratio within the mixing section during various feed conditions. The first metal AM contactor components have been fabricated using ANL's new metal printing capabilities as metal components can be used in high radiation areas. Meanwhile, contactor designs are being revisited in order to make them compatible with this new fabrication technique. While machined components are typical for bodies, some rotor design improvements will require AM fabrication. Activities conducted during FY19 were documented in a year-end report.

Efforts to upgrade the AMUSE code continue, with inclusion of species that are either currently absent or incompletely modeled that are of potential significance to the various fuels of interest. The specific species and required models are being identified through discussions with the INL team developing the pilot-scale system. (C. Pereira)

## 2.9 Early Design of Engineering Scale Demonstration

**[INL]** AECOM completed the detailed schedule for Conceptual Design and associated, refined cost estimate. AECOM also began reviewing the Code of Record created as part of Pre-conceptual Design studies for applicability to the Design Basis for Conceptual Design. The Conceptual Design contract was awarded by INL to AECOM on November 15th. Technology development planning work kicked off as well with a review of the objectives for the Demonstration and allocating those objectives to the major functions of the plant so as to align technology uncertainties as those are cataloged in the coming months. (K. Perry)

**[ANL]** ANL and INL personnel have held discussions on the separation factors to be used for process design determinations. The initial separation factors required reevaluation of the underlying processing assumptions in order to determine if the desired decontamination of the products could be achieved. The assumptions used to determine the separation factors will be reevaluated in tandem with new process modeling analyses. (C. Periera)

## 2.10Transportation

**[PNNL]** The conceptual HALEU transport definition was finalized in collaboration with ORNL and INL staff and material needs were established and documented in as much completeness as possible, a final deliverable, to allow timely specification of a certifiable large-volume $UO_2$ HALEU package (PICS:NE Deliverable M4FT-19PN030205032). It was delivered October 15, 2019. (H. Adkins)

***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]** NTD and Federal Program Manager participated in the ORNL MSR Workshop Oct 2-3, 2019. MPACT MSR safeguards and microcalorimetery work package managers, NTD, and Federal Program Manager presented safeguards activities related to MSRs. NTD and Federal Program Manager met with DOE/NNSA, ORNL management, and MSR campaign NTD to discuss coordinating efforts related to MSR safeguards, export control, and nonproliferation. NTD participated in the INMM-ESARDA Workshop on Future Challenges for the Enhancement of International Safeguards and Nuclear Security. NTD presented a summary of the MPACT program and emphasized the importance of a strong domestic Material Control and Accounting (MC&A) program for advanced nuclear fuel cycle development. MPACT and MRWFD NTDs held a call to discuss FY20 coordination efforts.

items.

## 3.2 MRWFD/Advanced Nuclear Safeguards and Security Research

### 3.2.1 MSR Safeguards

**[ORNL]** ORNL gave a presentation on MSR Safeguards at the ORNL 2019 MSR Workshop. Completed dose assessment comparing the dose rate from typical MSDR fuel salt samples with LWR fuel samples of interest to MPACT measurements. Interim reports are in preparation on the results of the dose assessment and the preliminary signatures work, which lays the foundation for the L2 milestone task and collaboration with SNL. ORNL hosted the PSU NEUP kickoff meeting with the PSU PI and Co-PIs, and SNL Collaborator in attendance. NEUP coordination has begun to grant the PSU PhD student access to the latest ORNL modeling and simulation codes, as well as granting the SNL PI access. Working to produce a list of samples and experimental setups for potential MPACT safeguards technology/ instrumentation measurements and test beds. The team met with PIs from the MSR Campaign to better understand experimental activities.

### 3.2.2 MSR Safeguards Modeling

**[SNL]** The MSR workshop at ORNL was attended to present safeguards-related work. This was an opportunity to coordinate the work with ORNL.

### 3.2.3 Microcalorimetry Consulting

**[LANL]** 23 samples from a UREX separation process were received from Argonne National Laboratory, and 8 samples from the H-canyon process were received from Savannah River National Laboratory. The samples are now approved for use and ready to begin measurements. These samples will be used to evaluate the microcalorimeter measurement opportunities in facilities that use aqueous separation processes. Installation of an improved control system for the SOFIA field test instrument has started. This control system will substantially improve ease of operation and will be important to enable the measurement campaign on recently received samples.

## 3.3 Safeguards and Security Supporting Technologies – Echem

### 3.3.1 Microfluidic Sampler

**[ANL]** All of the components for a custom-designed Raman system have been purchased and received. Bench-top assembly of the system and preparation of the required safety documentation are underway. The spectrometer is designed to be compact and portable to facilitate use with multiple emplaced systems, although the microfluidic sampler is the only project scheduled to use the system in FY20. The laser output and signal input of the system are coupled through a single fiber bundle, which will be fed into the glovebox containing the windowless optical flow cell.

### 3.3.2 Bubbler for Measuring Density and Depth of Molten Salt

**[INL]** The triple bubbler was installed into the HFEF ER just prior to the first Dresden LWR fuel batch through the ER. The bubbler operated continuously until after the first Dresden batch and U cleanup run. It was then pulled out for inspection and maintenance.

### 3.3.3 OR Voltammetry

**[INL]** The previous OR sensor from last year was missing the W electrode (broke off during operation). A new sensor was transferred in with SS and Ir working electrodes. The sensor was installed into the OR just prior to Dresden batch 2 run. CV measurements were acquired before, during, and after this batch. The sensor remained installed up until the middle of batch 3 when it was removed at the request of Steve Herrmann while he was troubleshooting low currant issues with the OR. The sensor was not the problem but it was not installed again until after the 3rd batch finished. The SciX conference (Palm Springs, CA) was attended and some of the lab scale OR voltammetry work from FY19 was presented.

### 3.3.4 ER Voltammetry

**[ANL]** A prototype version of the voltammetry sensor has been delivered to INL, along with the associated electrochemical instrumentation. Final operational guidelines are being developed for preparation into the documentation package that is to be delivered to INL in January, 2020.

## 3.4 Safeguards and Security Milestone 2020 – Echem:

### 3.4.1 Advanced Integration Methods

**[LANL]** The process of the new SSPM data for AI efforts on the microcal and HDND has begun.

### 3.4.2 Modeling and Simulation for Analysis of Safeguards Performance

**[ANL]** Performed calculations of electrorefining scenarios with the DyER (dynamic electrorefiner) model reflecting a range of process conditions, in order to identify system observables and trends that would indicate off normal conditions.

### 3.4.3 Security Facility Models

**[SNL]** The Security work was presented as part of the MPACT 2020 presentation at the INMM-ESARDA workshop in Tokyo, Japan

***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]** Completed the modifications to the Campaign work packages to incorporate the carry-over funds and establish activities for the funds. All the work packages have been submitted and approved.

[**INL**, **ANL**] Continued to develop the presentation material for the webinar on the TSRA work completed in FY 2019. Presented a dry run to campaign personnel and federal manager. The webinar date has been established as November 7.

## 4.2 NUCLEAR ENERGY SYSTEM PERFORMANCE (NESP)

### 4.2.1 Technology Maturity & Economic Performance Potential of Micro-reactors

**[ANL, BNL, INL, ORNL]** Started the collection of micro reactor information and held a meeting with HolosGen LLC to discuss potential collaboration on TSRA and ACCERT capital cost analyses. A formal request for collaboration was sent and the response is expected in November.

**[PNNL]** Conducted literature review of foreign energy transition policies.

### 4.2.2 Impacts of Foreign Energy Transition Policies

**[ANL]** Gathered publicly available data on the impacts of energy policy changes in Germany, Korea, and Japan.

### 4.2.3 Factors Impacting Nuclear Energy Share

[**ANL**] Started the collection of reference literature on the sustainability of nuclear energy in future markets and policy environments, from OECD/NEA, university, consulting companies, etc.

### 4.2.4 Maintain/Update of Fuel Cycle Catalog

**[SNL]** Data for two nuclear fuel cycles and for a reactor has been entered into the database, verified, and is now available on the public Nuclear Fuel Cycle Catalog. We worked with the SNL SharePoint team to diagnose problems they were having with SharePoint that were affecting entering data into the catalog, but not affecting the public Nuclear Fuel Cycle Catalog. We completed planning for FY20 activities in PICS-NE.

### 4.2.5 Transition Analysis Studies and Tools Development

**[ANL]** Development work continued on the DYMOND fuel cycle code to enable its efficient application for uncertainty quantification and sensitivity analysis for future fuel cycle deployment scenarios. Timing tests were also performed for DYMOND to determine the expected gains from planned improvements to the efficiency in the data logging and fuel depletion modules. Further effort was put into adapting the code to be more compatible with the DAKOTA coupling scheme, including running multiple scenarios in parallel. The revised DYMOND code is now being tracked with version control through GitLab.

**[INL]** We have been working with the local Powersim technical representative to identify the underlying factor behind why the VISION model would not function under Windows 10 and/or Office365. This issue has since been resolved (as of November). We are reviewing and editing portions of the NEA report on the TRU Management Benchmarking Exercise.

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

### 4.3.1 Improvement of ACCERT Algorithm

**[ANL]** Various activities are underway to improve the ACCERT algorithm, which include estimation of non-reactor facility cost, indirect cost model, factory fabrication cost model, and modular fabrication model.

**[INL]** INL staff coordinated with ANL staff assigned to this task and engaged in discussion to determine cost benchmarking case study. A non-reactor, fuel cycle case study is needed whereby the algorithms in ACCERT can be evaluated for gaps and performance in cost estimating non-reactor fuel cycle costs. Several possible case studies were suggested and are under evaluating to determine data sufficiency.

### 4.3.2 Daily Market Analysis of Load Following and Storage Impacts

[**ANL**] Requested quote from EnergyExemplar for commercial UC/ED code license to complement and confirm results obtained with in-house EDGAR model. Reviewed proposed economic activities from NREL.

### 4.3.3 Cost Basis Report Enhancements

**[ANL]** Developing proposals for public release process of the Cost Basis Report to release report effectively and frequently and continued to update and revise fuel fabrication cost modules in the Cost Basis Report.

**[INL]** Collaborated with ANL staff to outline plan for FY20. Discussions included how to streamline CBR release and how to get a website set up with a user interface for user feedback on the report. It also involved a review of which modules have been revised since the last major release so that these can be included in the revised method of release.

### 4.3.4 Regional and Global Analysis

**[PNNL]** Prepared topical areas and outline of potential journal articles for publication on future role of nuclear energy. Submitted summary of journal topics to NTD for discussion.

### 4.3.5 Lessons-Learned from LWR Deployment History

**[INL**] INL staff met with staff from BNL to discuss plans for this task. Staff circulated preliminary, background documents to develop initial approach for this work. Based on initial discussions, a draft approach is under consideration. It is based on identifying existing barriers to advanced reactor concepts then identifying lessons from history of LWR deployment that may be useful in overcoming identified barriers.

**[BNL]** Participated in kick-off telecom with INL to discuss initial thoughts on how to proceed with this activity. Also transmitted documents from the Atomic Energy Commission (AEC) to INL to provide historical background perspective.

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

# 5. JOINT FUEL CYCLE STUDY ACTIVITIES

The first 4 kg-scale electrorefining test with irradiated LWR fuel was completed in October. This test used irradiated LWR fuel previously reduced in the oxide reduction system. Tests confirmed initial results of >90% conversion of oxide fuel to metal.

The second 4 kg-scale oxide reduction system test with irradiated LWR fuel was completed. Initial data for this test indicates >90% conversion of oxide fuel to metal following oxide reduction and salt separation.

Fuel from an additional 8 irradiated LWR fuel elements was separated from cladding using the decladding equipment. This brings the total to 26 declad irradiated LWR fuel elements and provides feedstock material for four tests at 4 kg-scale.

An expert meeting on off-gas capture and pellet pressing was held at INL.

***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 TX, 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 provided information to the 2019 First Place winners who are presenting their award-winning papers at the Innovations in Nuclear Technology R&D Awards technical session, to be held November 18 at the American Nuclear Society Winter Meeting in Washington DC, and worked with ANS to set up the session. The session will be chaired by Dr. Andrew Griffith, Deputy Assistant Secretary for Nuclear Fuel Cycle and Supply Chain at the DOE Office of Nuclear Energy.

University Research Alliance assisted the Innovations Awards winners with their travel arrangements for the American Nuclear Society meeting.

University Research Alliance received desktop awards for the 2018 award winning students, which will be presented at the ANS meeting to those attending and mailed to the remaining winners.

University Research Alliance continued to update the Innovations Awards announcement distribution list in anticipation of the 2020 Innovations Awards.

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