INL/EXT-19- 55886

Nuclear Fuel Cycle and Supply Chain (NFCSC) Technical Monthly June FY-19

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Nuclear Fuel Cycle and Supply Chain (NFCSC) Technical Monthly June FY-19

1. ADVANCED FUELS CAMPAIGN

1.1 Advanced LWR Fuels

1.1.1 LWR Fuels

- **[LANL]** The Level 3 milestone titled, "Report on the effects of dopants on FLASH sintering of enhanced UO2," was completed. The report outlines the work conducted to assess the feasibility of flash sintering (FS) for grain enlargement of doped UO2. FS belongs in the group of field-assisted sintering techniques that use voltage and current to enable rapid densification in short timescales. The effects of field and current are not well understood yet, and, therefore, there is merit in continued assessment of when these techniques provide benefits beyond conventional sintering, as was done in this work. Doped UO2 samples with Cr additions both below and above the Cr solubility limit were fabricated via FS. The results of this work indicate that FS, although useful for rapid densification to high densities, is not a suitable technique for grain enlargement of doped UO2. This finding is linked to the low temperatures exhibited during FS and the short timescales that are utilized: minutes versus hours for conventional sintering. In particular, the low temperatures during FS likely inhibited Cr2O3 from going into solution into the UO2 lattice and, therefore, impeded grain growth for the doped UO2 sample with Cr additions below the solubility limit. Liquid-phase sintering could not have taken place during these FS conditions, and, therefore, the samples with high Cr content did not show any grain growth either. Instead, they formed second-phase particles that impacted densification and grain growth, as expected. Evidence of Cr2O3 secondary particles was identified both via backscatter SEM and EDS analysis. The proposed path forward is to assess FS of doped UO2 samples fabricated from feedstocks that incorporate the dopants into solid solution. Using such feedstocks would clarify the effects of dopant content and whether dopants going into solution is the mechanism by which grain enlargement is achieved. (E. Kardoulaki)
- **[ORNL]** Milestone M3FT-19OR020201053 titled, "Documentation Package Supporting Fabrication of Doped UO2 Samples for MiniFuel Irradiation and Fission Gas Release Benchmarking," due June 21, 2019, was successfully completed.

  The corresponding report provides an overview of fabrications of doped UO2 performed at ORNL using sol-gel feedstocks synthesized using a wet-chemistry route to ensure high dispersion of the dopant. This initial fabrication test focused on chromium given its widespread use to enlarge grains in commercial UO2. Samples were fabricated using conventional cold-pressing and pressureless sintering, demonstrated here to result in large grains and high pellet densities despite the small geometry necessary for MiniFuel (~3 mm diameter x 0.5 mm in height).

  This work provided samples for 12 MiniFuel capsules. These tests will focus on a single irradiation temperature and multiple burnups for each Cr content (2000 ppm, 1000 ppm) and reference UO2 samples. Initial efforts to measure fission gas release from particle fuels (bare TRISO/FCM kernels) have been successful, and so the next phase of MiniFuel will include monolithic pellet materials such as these, as well as U3Si2 fabricated by LANL. Post-irradiation examination of these pellets will provide unprecedented data on fission gas behavior for fuel irradiated at a constant temperature; this benchmark will be critical for BISON models as AFC seeks to increasingly utilize simulation to

inform design of MiniFuel and FAST irradiations. (S. Finkeldei, R. Hunt, J. Kiggans, C. Hobbs, B. Eckhart)

- **[ORNL]** An aerodynamic levitator with a controlled atmosphere capability has been installed and is operational. This instrument allows for containerless melting point and phase transition determinations at extremely high temperatures >3000°C. It can be useful for measuring melting temperatures of off stoichiometric materials such as UO2±x (J. McMurray)

1.1.2 LWR Core Materials

- **[LANL]** Microscale tests were performed on FeCrAl welds including microcompression and microshear specimens. The data shows very little change across the welds with some hardening related to residual stresses across the weld. Data has been incorporated in a report to meet a Level 4 milestone. (S. Maloy)
- **[LANL]** Characterization has been performed using EBSD and nanohardness on C26M tubing. Data comparison to that measured on other heats of C26M is in progress and will be incorporated into a milestone report. (S. Maloy)
- **[LANL]** TEM foils were FIBed from irradiated samples of PM2000 to investigate the defect densities after irradiation and correlate these microstructural defects with mechanical property data. The data shows that cracking was observed on the 001 planes resulting from texture formed during processing. Results were compiled to meet a L4 milestone. (T. Saleh)
- **[ORNL]** A total of 12 different ATF-FeCrAl alloy plates based on Fe-12Cr-6Al-2Mo-0.2Si, wt.% (C26M), with various combinations of minor alloying addition (Y, Zr, Ce, Mn, and C) have been prepared with a fully recrystallized microstructure. Controlled, refined grain sizes have been achieved by applying isothermal annealing at 800 or 900°C, depending on the combination of the alloying additions. The alloys are to be subjected to oxidation testing in a steam containing environment and room temperature tensile testing, to evaluate the effect of minor alloying additions on both properties. Machining the required specimens is currently in progress, and the tests are scheduled to be conducted in early July. (Y. Yamamoto)
- **[ORNL]** The fourth heat of C26M (heat #19055540, ORNL ID: C26M4), size 4.2 in diameter x 21 in long, has been delivered. The ingot is to be used as a master ingot for rod production through extrusion at ORNL. The visual inspection of the cross-sectional views indicated no solidification defect or crack formation inside the ingot. (Y. Yamamoto)
- **[ORNL]** The journal paper titled, “Elastic moduli reduction in SiC-SiC tubular specimen after high heat flux neutron irradiation measured by resonant ultrasound spectroscopy,” has been published. This study demonstrated resonant ultrasound spectroscopy as a nondestructive tool to evaluate micro-cracking damage of SiC composite tube following neutron irradiation with light water reactor relevant temperature gradient and neutron dose.

  Singh, G., Koyanagi, T., Petrie, C., Deck, C., Terrani, K., Arregui-Mena, J. D., & Katoh, Y., Elastic moduli reduction in SiC-SiC tubular specimen after high heat flux neutron irradiation measured by resonant ultrasound spectroscopy, Journal of Nuclear Materials, 523 (2019) 391-401. (Y. Katoh)
- **[INL]** The first batch PRW of MA957 ODS cladding + endplug with four weld conditions and five samples (A-E) was completed. All the PRW welded samples passed pressure burst test. An x-ray CT scan was performed on sample-C and E. Performed SEM, EBSD for grain orientation map and microhardness map across the PRW weld zone. TEM characterization was performed, and ASTAR grain orientation map from both weld and non-weld regions. APT analysis was conducted for high concentration small yttrium oxide particles for both weld and non-weld regions. Figure 1 shows as-

weld (top), pressure burst test (left) and the EBSD map of the PRW weld zone (right) with a scale bar of 90 μm. (J. Gan)

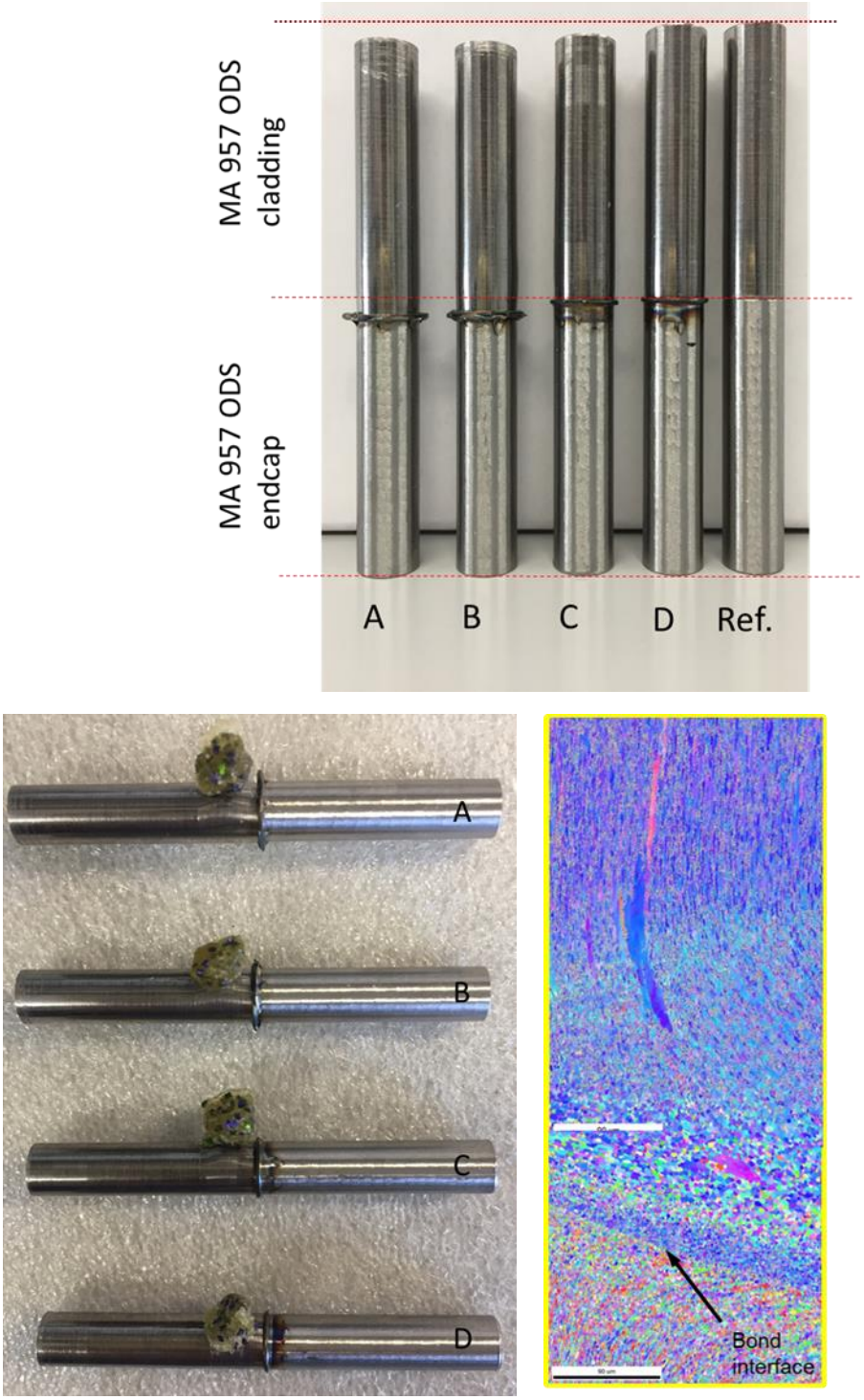

Figure 1. As-weld, pressure burst test, and the EBSD map of the PRW weld zone (right) with a scale bar of 90 μm.

1.1.3 LWR Irradiation Testing & PIE Techniques

- **[INL]** ATR completed powered axial locator mechanism (PALM) cycle 165A in June and began the cycle 166A outage. ATF-2 has 116 total EFPDs of irradiation to date and will began the next cycle of irradiation (166A) in July. Activities associated with the ATF-2 design change for ATR cycle outages 166B (addition of 6-pin holders with BWR-diameter pins at Tiers 3 and 4) and 168A (addition of a new 6-pin holder with PWR-diameter pins at Tier 5/6) continued. (G. Hoggard)
- **[INL]** As-runs/projections, basket loading configuration, and thermal analyses are making progress. These analyses are needed for the166A cycle. The anticipated 166A startup is forecast to begin mid-July. Fabrication of flux-wire monitor holders continues to make progress with a target to complete by end of fiscal year. Preliminary estimating/planning is in progress for new Framatome ATF-1 scope. Preparations are complete to ship ATF-18 to ORNL for furnace testing. Shipment is planned for early July. (C. Murdock)
- **[INL]** Disassembly of five ATF-1 capsules received at HFEF at the end of April was completed. The capsules contained rodlets from ATF-10 (U3Si2 fuel and Zirlo cladding), ATF-30 and ATF-34 (UN-U3Si2 fuel and Zirlo cladding), and ATF-41 and ATF-44 (UN-U3Si5 fuel and FeCrAl Kanthal-AF cladding). The first three rodlets were sponsored by Westinghouse, whereas the last two rodlets were sponsored by LANL. (F. Cappia)
- **[INL]** Visual examinations were performed on these five rodlets. Visual examination of rodlet ATF-10 is shown in Figure 2. (F. Cappia)

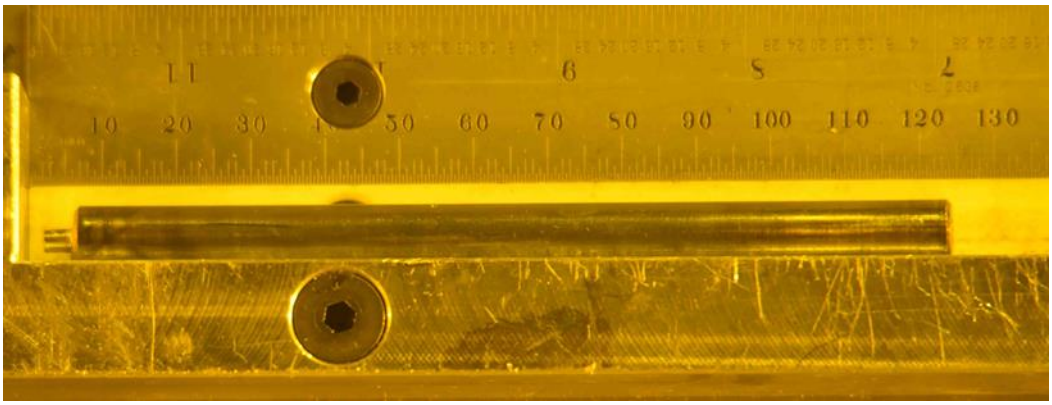

Figure 2. Visual examination of rodlet ATF-10.

1.1.4 LWR Fuel Safety Testing

- **[INL]** Fission gas samples from North Anna fuel samples were shipped to PNNL. Recovery work for disintegrated MET mount samples was initiated to assess microstructure with destructive PIE techniques. Work continued on BISON analysis work for future experiment development. Additionally, techniques to hydride zirconium tubes are ongoing. Various partial pressures of hydrogen were used to determine the hydrogen uptake in the samples. Samples have been sent off for hydrogen content analysis. Strength testing was also performed on the samples to determine the effect of the hydrogen on material properties. Techniques for hydrogen uptake in the samples continues to be explored. (L. Emerson)
- **[INL]** LOCA model runs were completed against furnace tests. (T. Pavey/L. Emerson)

- **[INL]** LVDTs were received from Halden to support testing of MARCH SERTTA. A subcontract was established with Boise State University to support characterization of thermocouple-cladding weldments. Instrumentation is being prepared for insertion into TREAT coolant channels next month. (K. Bowman)
- **[INL]** The Uranium Silicide irradiation test has completed final design and is currently being fabricated and assembled. Irradiation is expected to commence in the first week of August. (D. Dempsey)
- **[INL]** Preparations for the MARCH-SERTTA Final Design Review are nearing completion and the Design Review kickoff meeting is scheduled for July 18. This will support a September date for the initial MARCH-SERTTA vehicle commissioning irradiation test. (D. Dempsey)
- **[INL]** Milestone M3FT-19IN020204061, "Develop shipping strategies between facilities for TREAT experiments," was completed. (T. Pavey/H. Guymon)
- **[INL]** Computed tomography (CT) reconstruction for SETH D and E fueled rodlets was completed. The CT helps further destructive PIE. SETH D is pictured in Figure 3.

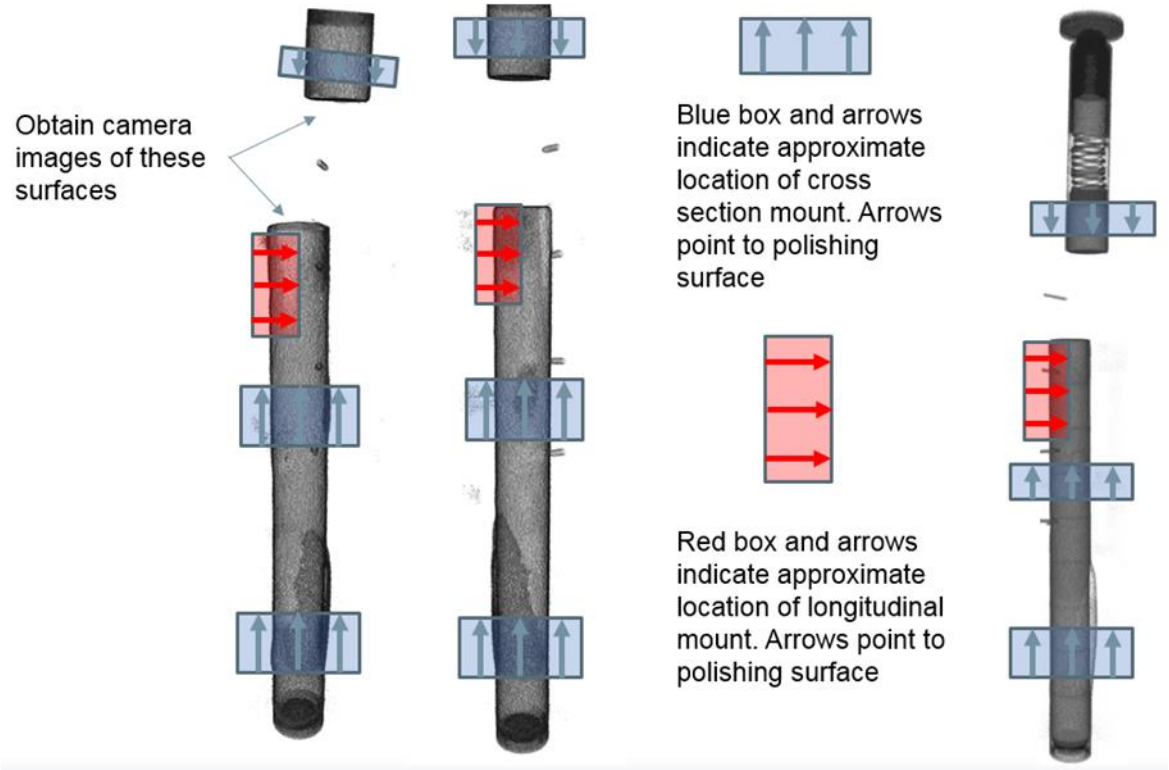

Figure 3. SETH D fueled rodlet.

- **[ORNL]** Milestone M3FT-19OR020204082, "Progress report on the measurement of fission gas release from irradiated fuel during temperature transients," was completed. The report summarizes present efforts at ORNL to develop a novel system to study the behavior of pores and bubbles in nuclear fuel which impact overall fuel performance during steady-state and transient accident conditions. The conceptual design of this system incorporates a high-temperature heated stage, a digital violet laser microscope, and collection of both real-time and integral fission gas release information using gamma and mass spectrometry techniques. While this system will offer new insights on fundamental knowledge gaps in current reactor fuels, another significant opportunity is applying transient testing methods to post-irradiation examinations of accelerated testing fuel geometries currently being developed under AFC (e.g., MiniFuel and FAST irradiations). By observing the performance of the nontraditional fuel geometries, transient testing will enable enhanced mechanistic models and ultimately provide insights on reactor applications of advanced fuels. (X. Hu, J. Harp, K. Linton, K. Terrani)

1.1.5 LWR Computational Analysis & Fuel Modeling

- **[BNL]** An examination of the response correlations for the uncertainty quantification (UQ) of the peak cladding temperature (PCT) in a loss of offsite power (LOOP) accident revealed a deficiency in the initialization of the sensitivity cases. The response correlation indicates a negative correlation between reactor power and the PCT. This unreasonable result was traced to the system response prior to the initiation of the accident. For each sensitivity case, a 100-sec null transient was run before the initiation of the LOOP accident. TRACE results indicated that in all 59 cases, by the end of the null transient, the system response had already brought the reactor power back to the nominal value, regardless of the value of the sensitivity parameters (reactor power being one of them) specified at time zero. Among the five remaining sensitivity parameters (fuel gap conductance, fuel thermal conductivity, clad thermal conductivity, clad-specific heat and fuel-specific heat) the two that show the highest response correlation to PCT are the gap conductance (negative) and the fuel-specific heat (positive). These trends are reasonable. A lower gap conductance and a higher fuel specific heat will both result in a higher stored heat in the fuel leading to a higher PCT subsequently.

  A Python script has been prepared to extract TRACE output for offline processing. The Python script can be modified to properly initialize sensitivity cases; i.e., achieving a different steady-state for each sensitivity case. This will bypass the restriction imposed by the SNAP interface for UQ that all sensitivity cases are to restart from a single steady-state. A trial of this approach is under development. (L.-Y. Cheng)

- **[BNL]** Neutronic analyses to support the assessment of the proposed accelerated testing approach for LWR fuels continued. The initial BNL calculations were performed for UO_2 full and half-diameter bare fuel pellets previously analyzed by INL using MCNP6.1 at beginning-of-life (BOL), and Serpent for the full depletion. The BNL MCNP and Serpent results for the radial relative power distribution at BOL, and the Serpent results at 300 EFPD for the full-diameter pellet and at 180 EFPD for the half-diameter pellet were in reasonable agreement with those from INL. Subsequently, INL has provided an MCNP input file that provides details of the modeling of the geometry outside the pellet; i.e., the entire irradiation capsule including the fuel pellet assumed in their analyses. The BNL models are being refined to incorporate these details. (A. Cuadra, M. Todosow)

1.1.6 Industry FOA

- **[ORNL]** Work has focused on performing a comparison of PRIME and BISON for low-power conditions to assess cladding constitutive models. This a preliminary step to establish comparisons of coated cladding tubes in BISON and ANSYS. GE-GNF is currently reviewing preliminary ARMOR constitutive models for accuracy. Additionally, simulations have been performed targeting the upcoming coated-cladding burst testing experiment. A summary of the sensitivity analysis of coating material properties performed for different coating thicknesses will be included in the upcoming milestone on BISON coating capabilities. (B. Wirth, R. Sweet)

1.2 Advanced Reactor Fuels

1.2.1 AR Fuels

- **[INL]** Work continued on FAST fabrication demonstration. Last month 8 FAST rodlets were loaded with sodium. This month the rodlets were loaded with either a steel or tungsten rod to simulate fuel slugs, and seal welded. After seal welding, the rodlets underwent settling and bonding operations. Two different methods were used: (1) vibrating the furnace containing the rodlets using a horizontal vibration table, or (2) vertically vibrating each rodlet using a modified vibro-peen tool. Based on radiographic results after bonding the individual vertical vibration was more effective in settling the fuel and the sodium on to the bottom of the rodlets. Based on these results, vertical vibration will be further optimized along with cooling schedules. Figure 4 below shows the typical rodlets after bonding. The slight discoloration is due to bonding in the air as opposed to bonding in a glovebox. With bonding finished, a Level 2 milestone was met to demonstrate fabrication of the FAST rodlets. Meeting this milestone shows that the FAST rodlets can be fabricated in an efficient manner that will allow the FAST test to be assembled on schedule. (R. Fielding)

Figure 4. Finished FAST surrogate rodlets.

- **[INL]** The thermal gravimetric analyzer with mass spectrometer (TGA-MS) was received from the vendor for installation in the thermal property cell (TPC) in the Irradiated Materials Characterization

Laboratory (IMCL). This will provide another tool for the characterization of irradiated fuels and materials. (J. Giglio)

- **[INL]** An outline and initial draft of the status report is underway. (C. Adkins)
- **[INL]** It was demonstrated using the modified hobby lathe in the AFCI glovebox in combination with different drill bits and geometries that differing shaped slots could be machined into Pu bearing fuel. This is important because it will allow for the machining of various shapes and sizes of slotted test fuels. It also supports completion of a Level 2 Pu machining milestone due at the end of FY-19. Figure 5 below shows an example of U-20Pu-10Zr fuel that was first machined to a smooth surface from the as-cast surface and then three different slot geometries were milled into the sample. Shown in the figure is a rounded slot, a triangular slot, and a square slot. In reality, all three slots would not be used. This shows the capability of the hobby lathe. (R. Fielding)

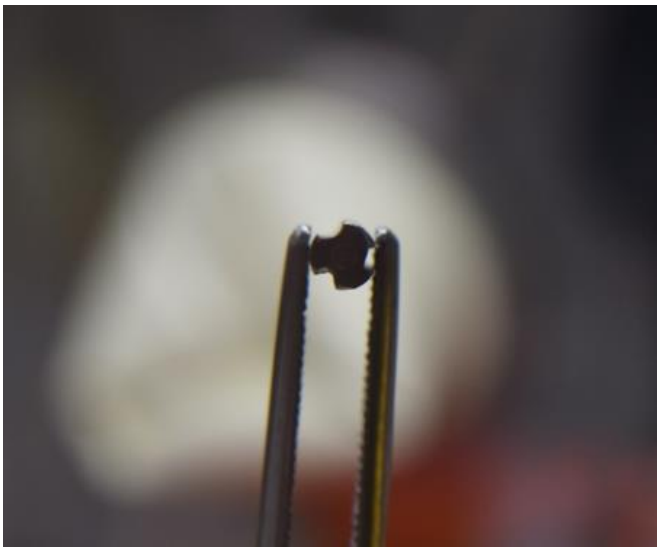

Figure 5. U-20-Pu-10Zr slug showing v, round, and square grooves.

- **[INL]** Work has progressed on characterization of co-extruded U-6Zr and zirconium, where the billet was fabricated by casting the U-6Zr directly into a 0.060-in thick zirconium can. This work was follow-on work to previously-extruded rods, although the can thickness was reduced by approximately 50%. The resulting extrusion went well. Metallography of a typical sample is shown in Figure 6 below. As seen, reduction of the zirconium can reduce the outer zirconium thickness down to approximately 150 microns (0.006 in). Although this is still thicker than what is needed for an FCCI barrier, the size can be further reduced by simply reducing the zirconium can thickness. (R. Fielding)

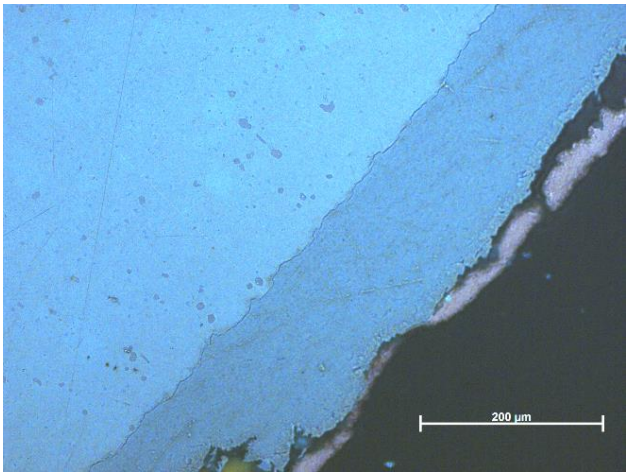

Figure 6. Typical cross-section and liner thickness of U-6Zr casting into a Zr can.

1.2.2 AR Core Materials

- **[PNNL]** Preliminary atom probe tomography (APT) examinations were completed on HT-9, irradiated at four different temperatures ranging from 375-460°C, and were compared to neutron irradiation response at 412°C. The temperature-shift theory would suggest that similarity in precipitate formation behavior between neutron irradiation at 412°C and ion irradiation should occur at only a slightly higher irradiation temperature of ~440°C. It was found that G-phase formation during ion irradiation at 440°C was most similar to that which forms during neutron irradiation at 412°C, lending credence to the temperature-shift theory. Alpha-prime, however, only formed during ion irradiation at 375°C at a very low size and number density, much different than the high-density that forms during neutron irradiation at 412°C. The reason for the different effect of ion irradiation on G-phase and alpha-prime may be due to a lower inherent stability of alpha-prime; i.e., it may be more sensitive to ballistic dissolution effects. These comparisons between neutron and ion irradiation highlight the importance of recognizing that ion irradiations are best used as a first-line screening tool for understanding irradiation effects and that neutron irradiations are needed at some point.
- **[PNNL]** Preparation for a lower dose rate ion irradiation on HT-9 began this month. A specimen was prepared and will be sent to Texas A&M University, where it is expected to be ion irradiated toward the end of July. This specimen will be irradiated to 37 dpa at one order of magnitude lower dose rate than other HT-9 specimens have been irradiated under this project. (M. Toloczko)
- **[PNNL]** Fractography using scanning electron microscopy (SEM) was completed for the J-R tested HT-9 steel specimens after various thermomechanical treatments (20 samples in total). The two HT-9 steels, respectively, with and without nitrogen addition after various treatments including as-rolled, quenched and single-tempered, and quenched and double-tempered were examined. Some high-strength specimens (i.e., under-tempered specimens tested at low temperatures [25 and 200 deg. C]), showed mixed -mode fracture with ductile dimples and cleavage facets. It was commonly observed for a variety of processing routes that the decrease of fracture toughness at high temperatures was associated with formation of shallow dimples. Further SEM analysis is underway for mapping the distribution of residual stress components and grain orientation in the microstructures after the same processing routes. (T.S. Byun)
- **[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 tubing establishes a unique R&D capability within the DOE complex.

Two pilgering runs on 14YWT, with each tube ending up about nine inches long, were completed earlier this fiscal year. Plans for next fiscal year are to extend this distance to 24-36 in. This will require a longer actuator and longer mandrels. The size of these longer components is currently being developed so that they can be procured and installed on the modified rolling mill. This revised setup will allow the longer pilgered 14YWT tubes to be obtained next fiscal year. (R. Omberg)

- **[PNNL]** A first draft of the milestone report, M3FT-19PN020302063 titled, "Characterization of Pilger Processed of 14YWT Tubing," due on August 15, 2019, is being developed. (R. Omberg)
- **[PNNL]** A tube of 14YWT was received from PNNL after pilger processing to a 9-inch-long tube. A one-in section was cut into ring pull specimens and tensile specimens along the tube. Mechanical testing is underway and will be compared to those results measured on other tubes made by pilger processing at CEA and tubes produced by hydrostatic extrusion at CWRU. (S. Maloy)
- **[ORNL]** Five new rods of OFRAC were extruded in May 2019 and the mild steel cans enclosing each extruded rod was recently removed. The ball milled powder for these extrusions were produced using an improved vacuum/Ar gas purging practice with the CM08 to reduce O and N contamination during ball milling. The final cans were cut to a length of 25 cm with a diameter of 2.2 cm. The Vickers hardness of the 5 rods was between 350-380 HV, which was close to specifications. The rods were shipped to Nippon Fuel Development (NFD), Japan for fabricating thin wall tubing using the high-precision tube roller (HPTR) approach. The significance of this next thin-wall tube fabrication attempt is that the final dimension of the thin wall tubing will be 6 mm outer diameter, 0.5 mm wall thickness, and lengths estimated to be more than 2 m. (Hoelzer/Massey)
- **[ORNL]** Three mild steel cans were fabricated for extruding ball milled powder of three new 14YWT heats that contain a lower 1%W content and different Ti additions of 0.2%, 0.3% and 0.4%. The 2 kg of ball milled powder from each of the three heats and extrusion cans are currently being welded and will be degassed under vacuum. The objective of these three new 14YWT heats is to determine if a better balance of strength, ductility, fracture toughness and creep properties can be achieve compared to previous 14YWT heats that contained 3%W and 0.4%Ti. (D. Hoelzer)
- **[ORNL]** The milestone M3NT-19OR020302051 titled, "Complete status report documenting the processing, microstructure and high-temperature mechanical properties of the nanostructured ferritic alloy OFRAC," was completed and submitted on June 30, 2019. The co-authors on this Level 3 milestone report were Caleb Massey (ORNL) and Rachel Seibert (ORNL). (D. Hoelzer)
- **[ORNL]** The manuscript titled, "Modern nanostructured ferritic alloys: a compelling and viable choice for sodium fast reactor fuel cladding applications," was submitted to the Journal of Nuclear Materials (Reference: JNM-2019-720) on June 18, 2019. The author and co-authors of this manuscript are: David Hoelzer (ORNL), Caleb Massey (ORNL), Steve Zinkle (UTK), Doug Crawford (INL) and Kurt Terrani (ORNL). (D. Hoelzer)
- **[ORNL]** The manuscript titled, "Friction stir welding of 14YWT thin plate," was submitted to the Journal of Materials *Processing Technology* (Reference: PROTEC-D-19-02095) on June 28, 2019. The author and co-authors of this manuscript are: David Hoelzer, Kinga Unocic, Phil Edmondson, Wei Tang, Zhili Feng and Maxim Gussev, all from ORNL. (D. Hoelzer)

1.2.3 AR Irradiation Testing & PIE Techniques

- **[INL]** The 166A irradiations cycle-specific analyses are making progress, with irradiations anticipated to start mid-July. AFC-IRT1 and one 4C capsule are planned to ship to PIE at the conclusion of the 166B cycle in early FY-20. The AFC-IRT2 and AFC-FAST group of experiments are planned to replace IRT1 and 4D in a later cycle. AFC-4D capsules will reside in canal storage post-168A until approximately start of CY2021, and then followed by shipment to PIE. The AFC-

FAST experiment group is in its final design phase with thermal analysis and fabrication development activities making progress. The project delayed final neutronics analysis due to resource constraints in order to support changes in ATF-2B and 2C project work. A baseline change was processed to reflect this. Cadmium is on hand to support future basket fabrication. (C. Murdock)

- **[INL]** Nondestructive examinations have started on 3 legacy EBR-II fuel pins taken from 2 unique experiments. These data will consolidate our understanding of the behavior of the metallic fuel and they will validate modelling and simulation tools like BISON and MARMOT. The 3 pins are:
  - X486-J555, U-10Zr, peak burnup 10at%, run with high temperature conditions compare to EBR-II driver fuel. This experiment is modelled also in the FIPD database so an active collaboration and "modelling driving PIE" exercise is in place with AFC modelling PI.
  - X496-CL39, X496-CL47: U-10Zr, average burnup 8.3at%, long life experiment, 59% smear density.
- Neutron radiography has been performed on all 3 pins and the X486-J555 is shown in Figure 7. The thermal neutron radiography on this pin does not present features of merit; its behavior is intended to represent EBR-II historical data. It is a pin from the set of qualification assemblies for the MK-IIIA design, X486 operating at two-sigma peak cladding temperatures. The PIE data will be used by fuel modelers. (L. Capriotti)

Figure 7. X-486-J555 pin.

- **[INL]** All materials for construction of the furnace fixture for in-cell (HFEF) fuel testing were tested and approved for assembly. The furnace fixture was assembled in the Fuel Conditioning Facility (FCF) mockup area. Development of the status report (Level 3 milestone) was initiated. (M. Cole)

1.2.4 AR Fuel Safety Testing

- **[INL]** The draft review of functional requirements document for the MARCH heat sink module was performed. Meetings were held to continue discussion on what experiment design will consist of as well as further solidifying the design team. Additionally, an engineer visited LANL for a knowledge transfer regarding techniques for achieving given enrichments and fabrication of fuel pellets in order to improve the fuel development process at the Materials and Fuels Complex. ***(L. Emerson)***
- **[INL]** IVEM experiments on Xe transport on batch with U alpha were performed. The U wires were completed. (T. Pavey)
- **[INL]** Successfully completed benchmarking M7. Continued to benchmark M5 and M6. (T. Pavey/L. Emerson)

1.3 Capability Development

1.3.1 CX Fuels

- **[INL]** The TPC glovebox passed the argon atmosphere acceptance test. Replacement is in progress of plastic gas and water lines in the glovebox with metal lines. Research personnel practiced loading/unloading of samples using manipulators. A new liquid nitrogen pump to replace the broken one has been ordered. The Phase III qualification plan for the TCM was initiated. The lab instruction (LI) for work control on the LFA and TCM was submitted for review. (M. Cole)

- **[INL]** The source laser has been coupled into a fiber to improve the quality of the pump spot. Data has been collected and is being analyzed. We will begin investigating different lens scenarios using the improved source spot profile. (D. Hurley)

1.3.2 TREAT Testing Infrastructure

- **[INL]** Design continued of the I position loop in-pile tube design. Design continued of the new closure head for ATR and the I position loop. (T. Pavey)

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

2. MATERIAL RECOVERY AND WASTE FORMS DEVELOPMENT

2.1 Process Chemistry and Integration

- **[INL]** The ongoing studies of a very promising actinide coordination reagent – bis(N,N'-methylpicolinate-ethylenediamine)-N,N'-diacetic acid (H4octapa) – present a thermodynamic balance capable of sustainable separation of trivalent actinides from trivalent lanthanides in aqueous mixtures containing ~0.25 M hydrogen ion. In this regard, the trivalent f-element complexation chemistry of H4octapa enables merging of actinide partitioning strategies proposed in United States and Europe. For the first time ever the proposed complexants (H4octapa and bis-triazolyl-pyridine) yield very comparable An3+/Ln3+ differentiation in aqueous conditions of similar acidity. The results of this study have been summarized in M2FT-19IN030102011 milestone report. (P. Zalupski)
- **[ONRL]** The ab initio molecular dynamics simulations show interconversion dynamics between two configurations of the Eu(III)-octapa complex. The change in a) potential energy, b) Eu-H_2O coordination number, and c) Eu-H_2O distances are shown in Figure *8*. In Config A, two water molecules are bound to Eu^{3+}; one of which departs out of the coordination shell at around 70 ps and forms an H-bond with a COO^- group, while the other water molecule remains bound to Eu^{3+}, as indicated by the Eu-H_2O coordination number and distances. Config A has the total coordination number of 10 (including Eu^{3+}-water and Eu^{3+}-ligand coordination), as similarly observed in the solid-state complexes with La^{3+} and Gd^{3+}. Config B, where Eu^{3+} has the total coordination number of 9, is energetically more stable in water. This is consistent with experimental measurements using fluorescent and NMR spectroscopy.

  Synthesis of a new batch of octapa is in progress to support the remaining characterization work and crystal growth. (S. Jansone-Popova)

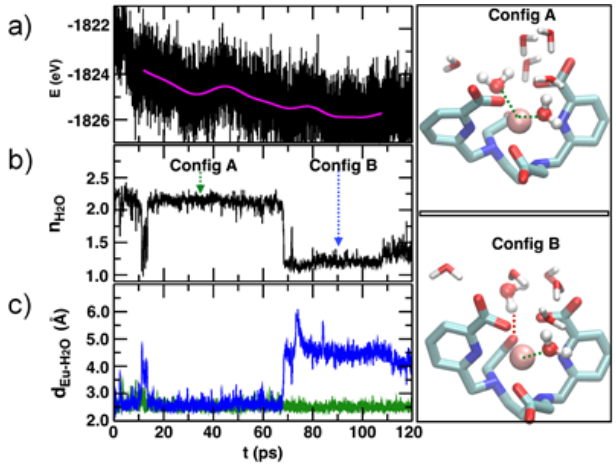

Figure 8. The change in a) potential energy, b) Eu- H_2O coordination number, and c) Eu- H_2O distances.

- **[PNNL]** An oral talk was given at the Northwest Regional Meeting of the American Chemical Society, (NORM'19) June 16-19, 2019, titled, "Two phase microfluidic measurements using micro Raman spectroscopy." It was presented by visiting Professor Gilbert Nelson, with coauthors Amanda Lines, Sam Bryan and Job Bello. Sam Bryan presented an oral talk at the National American Nuclear Society Meeting, in Minneapolis MN, June 9-12, 2019, titled, "Advances in online spectroscopic monitoring for application throughout the nuclear fuel cycle," with coauthors Amanda Lines, Gilbert Nelson and Job Bello. Both talks summarized various aspects of recent results of spectroscopic monitoring at the microfluidic Level. (Sam Bryan and Amanda Lines)

2.2 Waste Form Development and Performance

2.2.1 Electrochemical Waste Forms

- **[ANL]** A report documenting the results of analyses and initial tests conducted with iron phosphate glasses made at PNNL has been drafted and is being reviewed for issuance in July to meet a Level 4 milestone. Those tests indicated the intrinsic durabilities of the suite of glasses tested were similar to borosilicate HLW glasses and better than optimized glass-bonded sodalite materials that are the current baseline waste form for waste electrochemical process salt. Modified ASTM C1220 and C1285 tests are in progress to assess the effects of solution feedback on the dissolution of two glasses bounding the responses in ASTM C1308 tests. Those results will support a more complete comparison of alternative waste forms. (W. Ebert)
- **[PNNL]** Two milestones (M3FT-19PN030105072 and M2FT-19PN030105071) were completed in June that include recent work on iron phosphate glass waste forms for electrochemical salt waste simulants. In the submitted report, comparisons were drawn between these waste forms (and the overall process) and the glass-bonded sodalite as well as some of the other alternative waste form options that have been explored at PNNL (e.g., LABS glass and tellurite glass). The goal was to find an iron phosphate glass formulation with ≥ 30 mass% increase in waste loading over the baseline GBS and we achieved formulations of 370–510% greater that of the salt cation loading in baseline GBS (@8% salt loading). (B. Riley)

2.3 Glass Ceramics Waste Forms

- **[PNNL]** In June, PNNL published a paper in the *Journal of Acta Crystallographica,* titled "Syntheses, crystal structures, and comparisons of rare-earth oxyapatites $Ca_2RE_8(SiO_4)_6O_2$ (RE = La, Nd, Sm, Eu, or Yb) and $NaLa_9(SiO_4)_6O_2$," (see reference below). This paper documents the crystal structures of several oxyapatites and the changes in unit cell sizes as a function of lanthanides. This is useful for confirming and modeling the complex oxyapatites that form in the glass-ceramic waste form. (J. Crum)

  Crum, J. V., S. Chong, J. A. Peterson and B. J. Riley (2019). "Syntheses, crystal structures, and comparisons of rare-earth oxyapatites $Ca_2RE_8(SiO_4)_6O_2$ (RE = La, Nd, Sm, Eu, or Yb) and $NaLa_9(SiO_4)_6O_2$." Acta Crystallographica Section E **75**(7): 1020-1025.
- **[ANL]** Long-term modified ASTM C1285 tests are in progress with five reference glasses for DWPF HLW glasses and the international simple glass being used to compare results of testing and modeling activities in progress internationally. The purpose of these tests is to assess the effects of the solution composition on the on-set of Stage 3 and the Stage 3 dissolution rate. Both the solutions and grains of glass are being sampled periodically. As expected, Stage 3 was triggered soonest in tests with EA glass with leachants modified to high pH values. (W. Ebert)
- **[ANL]** The article, "Parameterizing a Borosilicate Waste Glass Degradation Model," summarizing the results of tests and modeling performed during FY-18, was accepted for publication in *npj Materials Degradation*. (W. Ebert)

2.3.1 Iodine Waste Forms

- **[ANL]** Tests with developmental HIPed AgI mordenite waste forms are in progress. (W. Ebert)

2.4 Domestic Electrochemical Processing

- **[ANL]** Characteristics of cell operation continue to be quantified to determine optimal conditions for kilogram-scale demonstrations of U/TRU co-deposition operations to be performed in FY-20. Large crucibles designed to collect the U/TRU product and facilitate subsequent sampling for analyses have been ordered; the current anode basket design can be adapted to accommodate the larger charge within the existing cell. (W. Ebert)
- **[ANL]** An abstract summarizing the design and representative results of electrochemical corrosion tests with Zircaloy-2 in molten LiCl-x% Li_2O salt was submitted for presentation at the 2020 TMS conference. These tests provide insights regarding the behavior of Zr during electroreduction and electrorefining operations. (W. Ebert)

2.5 Sigma Team for Off-Gas

- **[INL]** A long-term deep-bed adsorption test that was started in April 2019 continued through June. Silver zeolite is the sorbent in this test. The gas stream is a mixture of filtered, dry air with moisture added to achieve a dewpoint of 0 degrees C, with methyl iodide added to achieve a target concentration of 1 ppmv, and with no added NOx, to simulate a vessel off-gas stream.

  As of the end of June, the test duration was more than 1,400 hrs. Periodic gas sampling at the inlet and five bed segment outlet locations has confirmed that the inlet methyl iodide concentration is about 1 ppmv,; and that, as test time progressed, methyl iodide was detected in increasing concentrations first at the Bed 1 outlet (0.5 in deep), followed by Beds 2 and 3. By month end, the methyl iodide concentration at the outlet of Bed 1 approached about 90% of the inlet methyl iodide concentration.

  Methyl iodide also just started to break through Bed 4 (with a cumulative bed depth of 4.9 in) during June, but the methyl iodide concentrations in the Bed 4 outlet gas was still low at around 0.05 ppm. No breakthrough of methyl iodide from Bed 5 has yet been detected.

  This VOG iodine adsorption test is planned to continue for at least one more month, up to several thousand hours, or until periodic sampling and analysis indicates that (a) iodine concentrations in at least bed 1 reaches its maximum iodine capacity, or (b) breakthrough occurs in all five sorbent bed segments. (N. Soelberg)
- **[INL]** A report titled, "Evaluation of an Engineered Form MOF CaSDB," was completed meeting Level 4 milestone INL – M4FT-19IN030107019. The report documents capacity results in continuation of the development of engineered form metal organic frameworks (MOFs) using INL's composite formation procedure. After successful preparation of an engineered form CaSDB MOF, capacity tests were performed using the new engineered form. Initial breakthrough and saturation capacities are reported for xenon at room temperature and 253 K. The capacity results reported are in excellent agreement with previous capacity tests using earlier evaluated engineered forms. The latest composite form exhibits more robust material characteristics eliminating particle collapse and dusting effects, which are detrimental to sorbent capture systems such as sorbent handling and column over-pressurization. (T. Garn, M. Fujimoto, A. Welty)

- **[ORNL]** The tritium portion of the test plan for the off-gas capture system for advanced tritium pretreatment system was completed in May and the iodine tests and combined iodine / tritium tests were completed in June and an email was issued on June 25 confirming completion of the associated Level 4 milestone M4FT-19OR030107023, titled, "Complete testing NOx tritium pretreatment off-gas system for I and H-3 capture." The email stated that a series of 22 individual tests of the iodine and tritium capture system for tritium pretreatment have been completed. Many of the result for the tritium samples and a portion of the iodine samples have been received. Results from the initial tritium data resulted in modifications to the original test plan. Iodine sample results on the solid AgA and AgZ materials are pending from MURR. Preparation of the draft Level 2 milestone report is underway in parallel with the final tests. (R. Jubin)
- **[ORNL]** The draft Level 2 milestone report was issued on June 28, 2019. The issuance of the draft report completed on schedule the Level 3 milestone M3FT-19OR030107024 titled, "Prepare draft report on the design and testing of the advanced tritium pretreatment off-gas system to enable the quantification of the advance tritium pretreatment system tritium and iodine release performance." This report described the overarching goals of this activity as two-fold: The first goal was to demonstrate the recovery ability of both the iodine and tritium that would be released during tritium pretreatment (TPT) in a manner that the releases from the fuel can be quantified. The second goal was to demonstrate the combined recovery system that could operate on any of the three proposed TPT modes (once-through air or O_2, recirculating air or O_2., or recirculating NO_2). To accomplish this, a new iodine and tritium capture system was designed and constructed primarily of Hastelloy components. Using this system, a multifaceted test plan was completed. Twenty-two tests were completed: 10 tests examined tritium behavior under varying operating parameters, eight tests examined iodine behavior under varying operating parameters, and four tests examined both tritium and iodine behavior. With the data received thus far, the following conclusions can be drawn: (R. Jubin)
    - In even the simplest of the configurations (i.e., no sorbents in the columns), iodine is more difficult to recover from the system than tritium.
    - Tritium adsorbs to, and cannot be fully recovered from, the 10 cm column of silica gel, at regeneration temperatures up to 140°C.
    - Tritium also adsorbs to, and cannot be recovered from the 10 cm column of silver nitrate–impregnated alumina (AgA), at desorption temperatures up to 200°C.
    - Co-adsorbed tritium is more easily recovered from Ag-mordenite (AgZ) than from AgA, but recovery was not complete.
- **[ORNL]** The designed test matrix for aerogel was continued. A test exposing a thin bed of AgAero to 50 ppm CH_3I (balance dry air) at 135°C was completed. The loading curve is shown in Figure 9. The AgAero was observed to have an iodine capacity of 280 mg I/g AgAero under the test conditions. (R. Jubin)

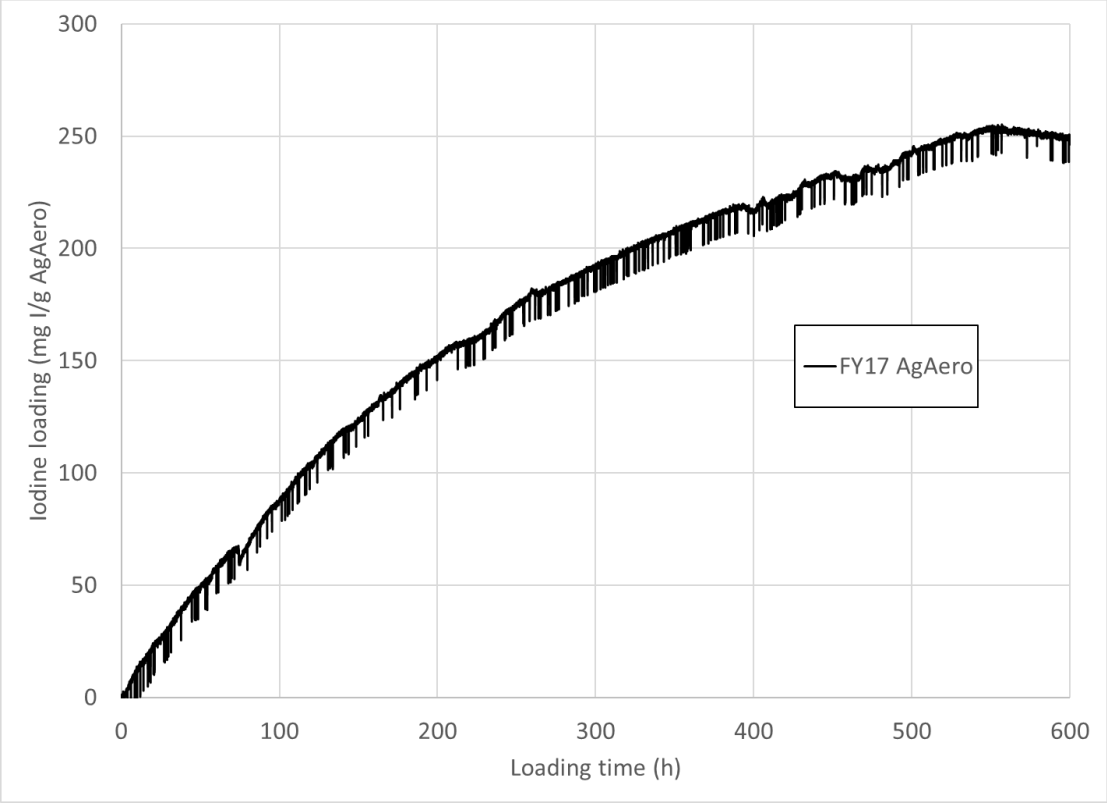

Figure 9. CH3I loading of AgAero.

- **[ONRL]** Two extended VOG tests were initiated on May 31. The first challenges a deep bed of Ag^0Z with ~50 ppb I_2 (balance dry air) at 150°C. The second challenges a deep bed of Ag^0Z with ~150 ppb CH_3I (balance dry air) at 150°C. Both tests remain online as of June 28, 2019. (R. Jubin)
- **[ORNL]** Silver-functionalized silica aerogel (AgAero) is a material proposed for use in the removal of iodine from the off-gas streams arising from nuclear fuel reprocessing. This material was developed by Pacific Northwest National Laboratory (PNNL). One of the challenges noted for AgAero as an iodine sorbent is its mechanical stability. Previous testing has shown that extended exposure to heated gas streams results in the degradation of the material such that the sorbent bed was compacted and a substantial quantity of fines were produced. PNNL has modified the material with the intention of strengthening the aerogel backbone and improving mechanical durability. A test similar to the previous test was initiated on March 13, 2019, to determine the behavior of the modified AgAero. Modified AgAero was exposed to a CH_3I-bearing humid gas stream for 84 days continuously. Testing was performed at 150°C with a superficial gas velocity of 10 m/min, a CH_3I concentration of 554 ppb, and an inlet dew point of 10°C. The density of the material increased by 16% over the course of testing and the height of the column was observed to decrease by 11%. The fines produced by the material were comparable to that of previously supplied material. Based on a limited set of test data, no distinguishable improvements were observed between the material produced in FY-17 and FY-19. The issuance of this report completed on schedule milestone M3FT-19OR030107025, titled “Complete extended duration (3 month) VOG test using reengineered Silver Functionalized Aerogel.”. (R. Jubin)
- **[PNNL]** The Level 4 Milestone (M4FT-19PN030107036) on fabrication of mechanically-robust low temperature MOF for Xe and Kr removal was completed. (P. Thallapally)

2.6 Flowsheet Demonstrations

- **[ORNL]** The draft report on the purification of the recycle Zr has been completed and submitted for ORNL review and approval. This report is in support of the associated milestone M3FT-19OR030206015. (R. Jubin)
- **[ORNL]** Shakedown tests of the 1.5 in lab-scale fluidized bed system have been completed and a report issued. The issuance of this report completes on schedule milestone M3FT-19OR030206017 titled, "Design, build, and conduct shakedown testing of 1.5" lab scale fluidized bed system.". The report summarizes the design, construction, and shakedown tests of the 1.5 in. lab-scale fluidized bed system in preparation for a series of comparative parametric chlorination studies using aluminum coupons and unirradiated aluminum-based nuclear fuel at a few selected conditions to determine the chlorination kinetics and the uranium conversion, retention, and losses. Preliminary runs were performed to shakedown the system and identify any needed modifications. The system performed satisfactorily, and except for a minor modification underway, it is nearly ready for the start of a series of comparative parametric chlorination studies. (R. Jubin)
- **[ANL]** A summary of flowsheet development and equipment development work to date was presented at the hybrid-Zircex/MRWFD planning meeting at the INL. AMUSE was used to run multiple flowsheets with slight variations as part of perturbation analyses to judge flowsheet stability with feed variability. The results indicated that the baseline flowsheet was stable for a number of cases involving small changes, ~±10%, in flowrate and acidity. The biggest impact was caused by changes in stage efficiency, as would result from use of small contactors or poor phase separation. For these changes, the output streams product recoveries were lowered significantly as the stage efficiency was reduced from the baseline case. The simulations indicated that the addition of various expected impurities had relatively minimal impact in most cases, which was unexpected. Because of problems running AMUSE on Excel 2016, we have been cleaning up the Fortran AMUSE code to fully replace the Excel version. The Fortran code runs well for essentially all species tested, except for an issue that impacts the output when Pu^{4+} and AHA are both included in the feed; in this case Fortran AMUSE does not converge, while Excel AMUSE does converge and yields the expected answer based on experimental studies. The log equation method for calculating speciation that was originally used in Fortran AMUSE was replaced with the simpler original method used in Excel AMUSE because of small but notable numeric inconsistencies between the results from the two codes. However, the linear solver that was used in the Fortran version was retained. Results generated by both codes are now self-consistent, and convergence is consistent. A more quantitative comparison of outputs is planned. In order to simplify comparison of multiple flowsheets with slight variations, the report generator that converts the XML Fortran results to tables and graphs in Excel was modified to either display the results immediately, or to allow the user to generate reports from multiple runs. (P. Candido)
- **[INL]** The INL HALEU program was awarded a GAIN voucher to identify and catalog used nuclear fuel (UNF) across the DOE complex. The information will be used to identify what sources of UNF can be used as feedstock for uranium recovery in aqueous reprocessing and serve as a source of HALEU in advanced reactors. (M. Patterson)
- **[INL]** The program completed a NEPA strategy document (consistent with an approved environmental checklist) documenting that an environmental assessment would compliantly address the NEPA requirements for an engineering scale demonstration of the Hybrid-ZIRCEX process. After successful demonstration of uranium recovery and conversion from zirconium- and aluminum-clad UNF, an environmental impact statement will be required if DOE decides to use the demonstration after the demonstration period. The demonstration period will be defined in a technology development and demonstration plan that is under development. (M. Patterson)

- **[INL]** Conducted preliminary dissolution experiments of depleted uranium metal in hydrofluoric acid to determine dissolution temperature and acid composition for dissolution of EBR II HALEU. Preliminary dissolution experiments are in preparation for dissolution of a 1.5 kg EBR II HALEU specimen in a small HALEU polishing demonstration. The polishing demonstration is anticipated to begin dissolutions by the end of the fiscal year and provide a small, research-scale specimen that meets the feedstock specifications for advanced reactor developers. (M. Patterson)

Figure 10. Dissolved DU metal samples.

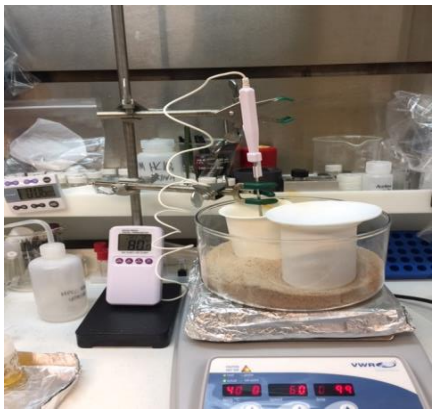

Figure 11. Dissolver setup for initial dissolutions of DU metal.

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

3. MPACT CAMPAIGN

3.1 Management and Integration

3.1.1 NTD & Management Support

- **[LANL]** NTD and Federal Program Manager held calls to coordinate FY-20 proposed activities with other DOE/NE campaigns. These calls with the MRWFD NTD and VTR NTD identified specific areas for MPACT to consider and develop as potential FY-20 activities.

3.2 Advanced Fuel Cycle Scoping

3.2.1 Advanced Process Modeling and Simulation

- **[PNNL]** Completed the evaluation of the ATM-109 fuel and nuclear forensics sample and are working to finalize assay results of the sister rod swipes and prep of the tank waste sample. Upon completion of these assays, the samples will be delivered to LANL for analysis using their microcalorimeter.

3.2.2 MSR Safeguards

- **[ORNL]** The first step of the parametric study has been completed, which shows the effect of variations in operational parameters (tolerances) on measurement parameters and isotopic inventory, which informs on potential measurements. The INMM paper was also completed and shows preliminary results from this early modeling work. This will be presented at the INMM Annual Meeting during July 2019.

3.2.3 MSR Safeguards – Modeling

- **[SNL]** Milestone MSR Safeguards Model and Analysis (M4FT-19SN040103051) was completed.

3.2.4 Advanced Fuel Cycle Scoping Review Panel

- **[ANL]** Assigned sections of the MPACT Advanced Fuel Cycle Panel scoping report were completed and provided to the NTD for inclusion in the full report. The draft report section included a discussion of electrochemical processing, CoDcon and Zircex.
- **[ORNL]** Supporting ongoing analysis and support for NMAC/ Safeguards and security assessment for identified fuel cycle technologies.

3.3 Safeguards and Security by Design – Echem

3.3.1 Microfluidic Sampler

- **[ANL]** Activities focused on the development of safety documentation for the molten salt sampling loop experiments, as well as follow-up with the foundries and fabricators working on the system build.

3.3.2 Actinide Sensor

- **[INL]** Water cleaned some U-membrane tubes (0.5mm wall thickness) that were ion exchanged in pure UCl3 at a lower temperature, unexpectedly some cracks were found in the U-membrane tubes. Analysis and understanding of the cracks are ongoing. More U-membrane tubes with thicker wall (1.0mm) are being fabricated by ion exchange in pure UCl3 and relatively short ion exchange time will be used to mitigate the cracking issue. In parallel, some high strength Na-beta" alumina membrane discs (provided by Materials and Systems Research, Inc.) were ion exchanged in pure UCl3 and a special U-sensor design for testing the high strength U-membrane is being prepared.

3.3.3 Bubbler for Measuring Density and Depth of Molten Salt

- **[INL]** The bubbler cleaning flow loop was fabricated and tested in mock up. The system performed as expected and was transferred into the decon cell in HFEF. The plan is to transfer the bubbler out of the argon cell into the decon cell to perform the cleaning procedure. The initial cleaning test will be performed when operator time is available. Water testing using the different bubbler tip designs and orifices continues, in order to provide input toward building a new bubbler that is less prone to salt plugging. Following the water test, molten salt tests are planned to further provide input toward a better bubbler design.

3.3.4 ER Voltammetry

- **[ANL]** Fabrication of the voltammetry sensor for installation into the INL IRT electrorefiner is nearing completion. Experimental operations in ANL's electrorefiner are continuing, in order to prepare for the transition to Idaho.

3.3.5 OR Voltammetry

- **[INL]** Performed a number of tests in the laboratory to test a new sensor design using iridium as the working and reference electrodes. In the tests, the sensor was tested first in a base LiCl salt. From the CV, there may be some minor alloying between the Ir and Li metal when operating in the cathodic potentials. In the anodic potentials, the Ir looked great. Incremental additions of Li2O were added to the salt. In the anodic potentials, an O2 peak was observed just prior to Ir dissolution. In the cathodic potentials, the Li reduction potential shifted noticeably with each addition and varied significantly vs the Ir reference electrode, which is expected as it is a psuedo reference electrode, and either Li reduction or Ir dissolution potentials will be used to normalize the CV as part of post-processing. Some tests were performed to electrochemically remove the impurity from Li2O in the salt using sacrificial electrodes (stainless steel as working electrode and glassy carbon as the counter electrode). The tests confirmed the contribution of the moisture in CVs, showing that understanding the CV with or without the common LiOH features is desired. Tests are ongoing to further explore the Li2O contribution using the current sensor design.

3.4 Modeling Advanced Integration and Milestone 2020

3.4.1 Advanced Integration (Models)

- **[SNL]** Modifications to the AMPYRE code have been successfully completed to allow for flexibility in the configuration of individual unit operations with respect to pre- and post-cycle processing and material transfer timing. Variables that account for the dynamic availability of accountable material between unit operating cycles have been included in the model, along with corresponding functions that manage each unit's operation. These new features can be applied for both pre- or post-cycle status

of the equipment and/or material such as loading/unloading, preheating/cool down, material transfers, confirmatory measurements, etc. Mass balance for model results has been verified for the facility, for individual unit operations, and for each component tracked in the model. Utilities have also been added for visualizing unit operation timing and unit mass balances for U, Pu, and bulk mass.

3.5 Exploratory Research/Field Tests

3.5.1 Microcalorimetry

- **[LANL]** The team successfully completed the Field Test Instrument milestone (M3FT-19LA040106012). Initial results from the instrument (SOFIA: Spectrometer Optimized for Facility Integrated Applications) are extremely promising. As documented in the milestone report, major performance metrics like readout noise and energy resolution match those achieved in the larger cryostat systems. Because of the compact geometry, detection efficiency for small samples has been increased by approximately a factor of 4 compared with the previous system. The development of SOFIA has significantly advanced the technology readiness level of ultra-high resolution microcalorimeter gamma spectroscopy. Continuing to work with INL, ANL, and PNNL to identify and package samples for shipment to LANL as part of the user assessment. Katrina Koehler is finalizing revisions to her thesis and will be presenting MPACT work at the 18th International Workshop on Low Temperature Detectors.

3.5.2 High Dose Neutron Detector

- **[LANL]** The MiniHDND test assembly was shipped from INL back to LANL with initial feedback. INL suggests the need to replace the top connector to better support remote handling. LANL will pursue this with PDT in the follow-on activity. The present test assembly was shipped to PDT to be re-used for manufacture of the fully functional prototype in line with milestone M3FT-19LA040106023. Currently, the final first prototype unit is expected in the late September timeframe.

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]** The proposed activities for FY 2020 submitted by the SA&I lab collaborators were evaluated and prioritized. External consultations with other NTDs also took place to ensure that planned activities are consistent with future directions of the campaigns.

4.2 Equilibrium System Performance (Esp)

4.2.1 Performance of Fuel Cycle Systems

- **[ANL]** T. K. Kim attended the "Micro Reactor Workshop" hosted by GAIN, EPRI, NEI, and USNIC, June 18-20, 2019, at INL, and collected information on microreactor concepts. Eleven micro-reactor concepts were discussed during the workshop, which were grouped into gas-cooled, heat-pipe, and lead-cooled fast reactors. All the proposed microreactor concepts (based on once-through fuel cycle) require HALEU. The target markets are remote civil and military locations with power requirement of 1-10 MWe.
- **[INL]** Work to evaluate impacts of using a range of LEU/HALEU enrichment Levels in LWRs is in progress.

4.2.2 Economic Analysis Capabilities and Assessments

- **[ANL, INL]** Submitted the Level 2 milestone report, "Report on the ACCERT Cost Algorithms Tool," by F. Ganda, et al. The objective of this work was to improve the fidelity of the ACCERT (Algorithm for the Capital Cost Estimation of Reactor Technologies). The feasibility of ACCERT had been demonstrated in previous work. Newly accomplished elements in FY-19 included: cost models for the Nuclear Steam Supply System (NSSS) including via comparing historic data, cost models that contribute at least 0.5% of the total direct costs, and the quantification of uncertainties of the cost estimates.
- **[ANL]** E. Hoffman attended the OECD/NEA Expert Group on Uranium Mining Economic Development (UMED), June 17-19, 2019, in Paris. The overall content and format of the final report of the group was discussed, including the planned content for the business and capacity development sections to be led by ANL.
- **[ANL, BNL, INL**] Draft sections of the report on impacts of private versus public construction were provided by K. Biegel (University of Wisconsin) and A. Gascon (BNL). Some key reports were found by J. Hansen (INL) on megaprojects and pioneer plants as part of his literature search. Most of the key sections of the report are nearing completion. A call was organized for next month to provide a status report to management and to discuss the target audience and objectives for the final report.
- **[INL]** To support the literature study on cost overruns, separated out by public versus private management, additional studies were gathered from RAND Corporation and from the literature on megaprojects. Nuclear projects fit within the literature space of megaprojects, so these new sources provide important information relative to the general theory of managing large scale projects. Review of these additional documents revealed three general issues facing management of megaprojects: (1) uncertainty and proper estimation thereof, (2) stakeholder management, and (3) contract management. These insights have been incorporated in the draft writeup, which documents the findings of the literature study.

4.2.3 Enhancements to the Cost Basis Report (CBR) Tool

- **[ANL]** Transferred the information on the cost-basis report to E. Hoffman from F. Ganda and continued the discussion and review of the ongoing work of K. Williams to update the HALEU-containing fuel fabrication module.

4.2.4 Analysis of NES to Augment Information in Fuel Cycle Catalog

- **[ANL]** The draft of the example case (deployment of a fast closed cycle U/TRU SFR-based system and a thermal once-through U/Th MSR-based system) was largely completed. The largest implications for the government are based on objectives of the government, particularly in HLW/SNF management. As envisioned, the two systems will have very different HLW/SNF, one being a minimum TRU containing HLW and the other being molten-salt spent-fuel containing both TRU from the irradiated LEU component and all the long-lived components of the thorium component, as well as some likely HLW from the processing systems employed. Very different and complex waste stream are expected. There are other important considerations and impacts being evaluated.

4.2.5 Maintain/Update Campaign Analysis Tools

- **[SNL]** We received new fuel-cycle option data and data for a reactor in late March and are creating the interactive flow diagrams for the two options.

4.2.6 Campaign Special Sessions at International Topical Conference

- **[ANL]** The SA&I Campaign will host five technical sessions and one panel session during the GLOBAL 2019 conference in September 2019. The session chairs were assigned and panelists were recruited. During the panel session, the sustainable strategies for nuclear energy systems under future energy market environments will be discussed.

4.2.7 Beyond Levelized Cost of Electricity

- **[INL]** BLCOE leadership activities - Briefed Madeline Lefton, the new NE representative on the BLCOE Executive Committee, about the project. Participated in the BLCOE Executive Committee meeting on 6/27 as part of the leadership team. Membership has swelled and six offices were represented (NE, FE, EERE, OE, OP, EIA). Finalized re-planning of the software screening and evaluation activity as previously requested by the Committee and presented the new plan at the meeting. Participated in a two-day kick-off workshop to implement the new plan. Continued to participate in occasional webinars to review work in progress, bi-weekly coordination calls with task leads, weekly coordination calls with our DOE counterparts and more frequent calls within the leadership team as needed.
- **[INL]** Continue to grow the ARMA algorithm to handle clustering by signal attributes more consistently. Beginning to Identify a demonstration case for valuing various units in an energy profile individually.

4.3 Development, Deployment and Implementation Issues (DDII)

4.3.1 Technology Development Roadmap for a Continuous Recycle System Using Fast Reactors

- **[ANL, BNL, INL, LLNL]** Submitted the milestone report, "Report on a Technology Development Roadmap for a Continuous Recycle System with Fast Reactors Using the Technology and System Readiness Assessment Process," by B. Dixon, et al. The report documents efforts conducted this year to develop a process and reporting format for creating technology maturation plans and rolling those plans up into technology development roadmaps. The process was tested on an advanced nuclear fuel cycle based on fast-spectrum reactors and continuous recycling of U/TRU (an example of the EG24 fuel cycle evaluation group). The performance requirements for the reactor, fuel, and reprocessing systems were selected to require advanced technologies needing further R&D so as to test the Technology and System Readiness Assessment process.
- **[ANL]** As the part of the M3 milestone report, “Report on a Technology Development Roadmap for a Continuous Recycle System with Fast Reactors Using the Technology and System Readiness Assessment Process,” the technology maturation plan and rolled-up technology development roadmaps of Advanced Sodium-cooled Fast Reactor (ASFR) with the recycled U/TRU metallic fuel were completed.
- **[LLNL]** W. Halsey provided an independent technical review for delivery of the INL milestone (M3FT-19IN120103031) report, "Report on a Technology Development Roadmap for a Continuous Recycle System with Fast Reactors Using the Technology and System Readiness Assessment Process,” that included authors from INL, ANL, and BNL.

4.3.2 Transition Analysis Studies

- **[ANL, INL, ORNL]** Participated in Technical Workshop on Fuel Cycle Simulation (TWoFCS) at University of Illinois – Champaign-Urbana from June 26-28. Analysts from the campaign presented seven talks on the campaign’s work on fuel cycle code development, benchmarks, transition analysis, and fuel cycle economics. They were well-received by the domestic and international academic and research communities who were present, most of whom are world experts in fuel cycle systems modeling.
- **[INL]** Made three presentations related to campaign activities at the Technical Workshop on Fuel Cycle Simulation (TWoFCS) in Champaign, Illinois. The first was about modeling for improved recovered uranium utilization, featuring updates in the VISION model. The second was a recap of results for the NEA TRU management benchmarking activity (again using the VISION model). The third was a review of a study on improving the economics of an EG-23 and EG-30 transition scenario by utilizing LEU startup to optimize separations facility utilization factors.
- **[ORNL]** Two ORNL team members attended the 2019 Technical Workshop on Nuclear Fuel Cycle Simulation (TWOFCS); Eva Davidson and Jin Whan Bae. The attendance included a presentation on “ORION Fuel Fabrication method validation with SCALE/TRITON” which was produced in collaboration with the UK National Nuclear Laboratory (the ORION developers).
- **[ORNL]** Three conference papers have been produced and are undergoing internal review before submitting to the organizers. They are: “ORION Fuel Fabrication Validation” for Global 2019, and two ANS Winter Meeting summaries, “MSR uncertainty analysis for fuel cycle assessments,” and “Implementation of a MOX Neural Network for Fuel Cycle Modeling”.
- **[ORNL]** Eva Davidson has been asked to Chair one of the Fuel Cycles sessions at Global 2019. In this capacity, she has reviewed and provided feedback on five session papers.

- **[ANL]** The DYMOND fuel cycle code was moved from the Stella Architect platform to AnyLogic in order to enable coupling with external depletion codes such as ORIGEN and a novel hybrid approach of using both agents and continuous flows to model the fuel cycle. This flexibility has enabled many additional modifications/improvements to the DYMOND code, which is part of the Campaign's state-of-the-art fuel cycle systems modeling capabilities.
- **[ANL]** Initial studies have been performed in sensitivity and uncertainty analysis of time-dependent fuel cycle scenarios. Sensitivity calculations were performed on example scenarios of transition to determine the impact of variables with high uncertainties (fast-reactor start date, recycling time, fast/thermal reactor fleet shares) on important performance metrics of transition. Application of such approaches will allow quantification of confidence/ uncertainties of any simulated results for future fuel cycle scenarios that are presented by the Campaign**.**
- **[ANL, INL, ORNL]** Continued to participate in the two fuel cycle modeling benchmarks through the OECD-NEA Advanced Fuel Cycle Scenarios Expert Group and FIT Benchmark activity (organized through the TWoFCS framework) to promote US fuel cycle modeling capabilities and expertise.
- **[ORNL]** To demonstrate and test the ORION results for the Functionality Isolation Test (FIT), a python script was produced that automatically calculated the Effective Fissile Mass Coefficient (EFMC), the method used in ORION, for 10,000 Pu vector samples**.**
- **[ORNL]** A first preliminary draft of the M3 report, "Application of Cyclus to a Transition Scenario" has been completed and comments incorporated. Additional survey results were solicited at the recent TWOFCS meeting (PNNL and other Cyclus developers).

4.3.3 Adaptation of OR-SAGE for NES Analysis

- **[ORNL]** Work has continued on the development and evolution of the GIS mapping assessment. The data processing for siting fuel cycle facilities is ~60% complete and work is now underway on the logistics framework for the fuel (fresh and spent) transportation optimization. In parallel, the server set-up for the simulation environment is being finalized. Additional ideas have been considered and generated for how to most appropriately evaluate the existing non-nuclear sites and the national labs using SMR parameters already available in the existing OR-SAGE siting tool.

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

5. JOINT FUEL CYCLE STUDY ACTIVITIES

- Evaluated the condition of the received IFSF-stored LWR fuel at HFEF. Inspection showed that the fuel was intact and water free allowing for the next steps in processing.
- Performed a second Oxide Reduction System test at a 4 kg scale (~2 LWR rods).
- Continued several Critical Gap Research and Development activities at HFEF in support on ongoing IRT activities.
    - LiCl crystallization experiments.
    - Metal and ceramic waste form experiments.
    - Electrorefiner salt sampling experiments.

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

6. AFCI-HQ PROGRAM SUPPORT

Site: University Research Alliance at West Texas A&M University in Canyon 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 Michigan, 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 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 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 continued processing award checks for the 2019 Innovations Awards winners.
- University Research Alliance submitted letters of congratulations for the award winners to the DOE, to be signed by a DOE official, which will be included with the award checks.
- University Research Alliance continued to prepare press releases on behalf of the 2019 Innovations Awards winners. Winners' university department heads, advisors, and newspapers are among those who are formally notified of their achievement.
- University Research Alliance continued to collect information to post the 2019 Innovations Awards announcement on the nucleartechinnovations.org website.
- University Research Alliance assisted First Place winners in submitting summaries for the Innovations Awards special session at the ANS Winter Meeting in November. All of the summaries are on track to be submitted by the ANS extended deadline of July 8.
- University Research Alliance continued to update the Innovations Awards announcement distribution list and remove people who have asked to be removed from the list.

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