NTRD
Technical Monthly
November FY19

Nuclear Technology Research and Development

Prepared for
U.S. Department of Energy

January 11, 2019

INL/EXT-19-52452

CONTENTS

FIGURES

ADVANCED FUELS CAMPAIGN

NUCLEAR TECHNOLOGY RESEARCH AND DEVELOPMENT TECHNICAL MONTHLY NOVEMBER FY19

Advanced Fuels Campaign

ADVANCED LWR FUELS

LWR Fuels

- **[ORNL]** Preliminary runs and process improvements continue for the first-generation microfluidics based columnless sol-gel system with in-line feedstock mixing to produce cerium oxide microspheres with tighter tolerances. Output is currently ~0.5g/hr of gelled beads. Approximately 40 grams were produced and characterized during the week spanning 12/03/2018-12/07/2018. Results are shown in Figure 1 and Figure 2 below. (J. McMurray)

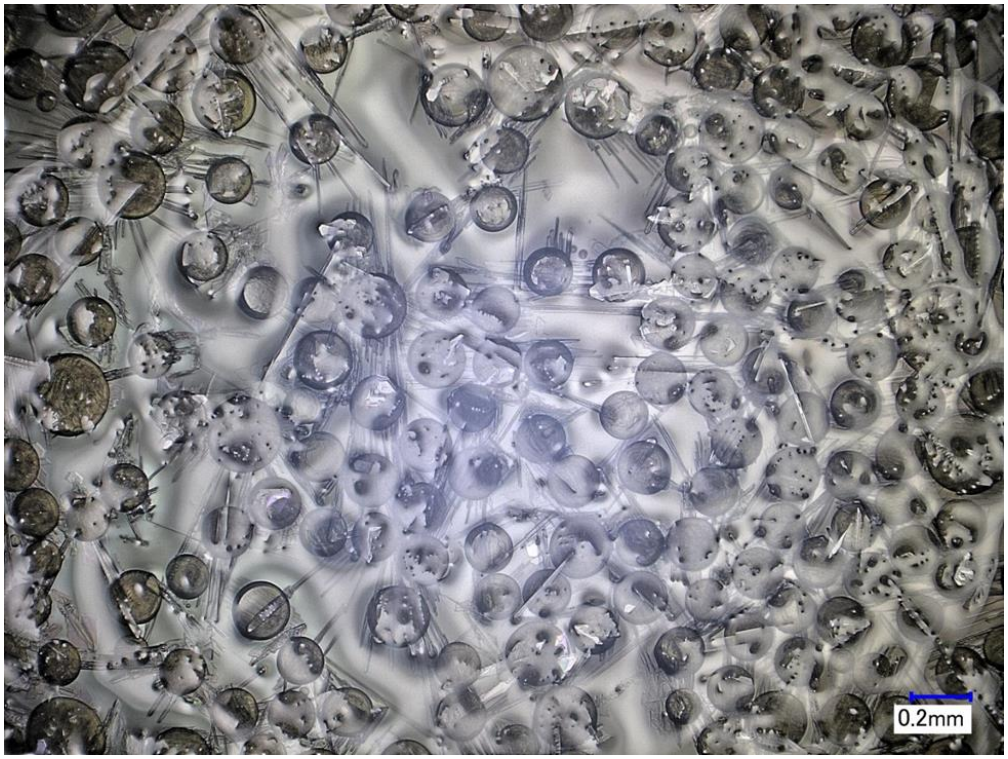

Figure 1. Sample of gel spheres collected from batch run 12-05-2018. The beads are encased in dried gelation media. Cleaning is underway for the ~40g collected for improved characterization of air-dried beads and subsequent conversion to ceramic and characterization thereof.

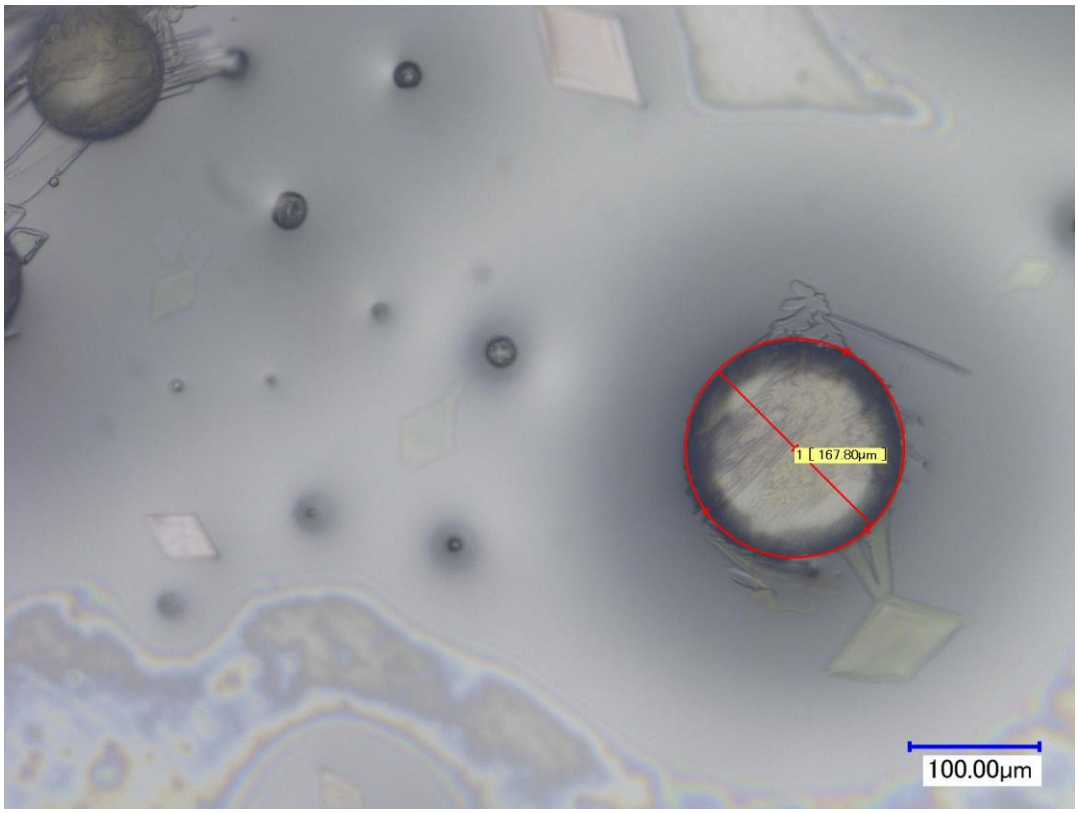

Figure 2. A 167.8 µm Ce oxide gel sphere. The image was taken with a Keyence optical microscope in the LAMDA facility at ORNL.

- **[ORNL]** Synthesis of important FeCrAlO spinel compositions continues. Measurements have been conducted using NOMAD at Spallation Neutron Source (SNS) at ORNL and the Advanced Photon Source (APS) at ANL to understand crystal chemistry and phase equilibria of already synthesized compositions. Planning for calorimetry at ORNL and UC Davis continues to determine thermochemical properties. Analysis of the data collected to date is underway to determine phase equilibria and short range ordering in Fe-Cr-Al-O spinels to be used as inputs for physics based thermodynamic modeling. (J. McMurray)

LWR Core Materials

- **[LANL]** A fixture was machined for performing shear punch testing on the flat heads of dog bone tensile specimens. This will be used for performing shear punch testing on FeCrAl tensile specimens for direct comparison of irradiated tensile data with irradiated shear punch data. (T. Saleh)
- **[ORNL]** Preparation of master rod/plate C26M2 samples (heat #17025001, Fe-12Cr-6Al-2Mo base, ATF wrought FeCrAl alloy) for hydrogen diffusivity measurement was initiated. A previously prepared C26M2 rod with 0.6-inch-diameter, produced by an extrusion at ORNL, exhibited inhomogeneous grain structure containing non-recrystallized grains. Fully recrystallized microstructure was obtained after annealing at or above 1050°C, although the grains were coarsened significantly (~200 µm at 1050°C and ~300µm at 1200°C). For preparation of the same C26M2 sample with relatively small grain size, the C26M2 tubes with uniform grain structure (average ~40 µm, in as-received condition) were warm-forged and -rolled at 200°C to obtain the flattened sheet samples with ~0.35 mm in thickness. Because of plastic deformation applied during the flattening process, a little grain coarsening was observed after annealing at 900°C for 30 min. However, they

maintained uniform, fully recrystallized grain structure with ~50 μm grain size. The annealed rods and the sheets will be machined into multiple disk specimens for hydrogen diffusion measurement study. (Y. Yamamoto)

- **[ORNL]** Microhardness testing was completed on tensile and fracture toughness specimens of FeCrAl alloys at ORNL's IMET facility. Testing included FeCrAl specimens with various compositions and microstructures irradiated near 7.5 dpa at 236, 282, & 460°C. Microhardness testing will enable for accurate fracture toughness testing in-cell as well as the development of structure-property-property relationships for irradiated FeCrAl alloys. Micro-tensile specimens have been prepared for shipment to ORNL's LAMDA facility for in-situ testing. (K. Field/X. Chen/D. Zhang)
- **[ORNL]** The full database from the FY18 FeCrAl Handbook has been assembled into a single spreadsheet document to enable rapid dissemination of the data to researchers, industry, and regulators. The spreadsheet can be provided on request. The database is also being explored for deployment on a web-based app to enable ease-of-use. (D. Richardson/K. Field)
- **[ORNL]** The objective of the High-dose neutron irradiation of SiC composites task is development of irradiation resistant SiC composite materials for advanced reactors. Flexural test of chemical vapor infiltrated SiC composites reinforced with Tyranno SA3 fibers coated with single layer pyrolytic carbon (PyC) interphase was conducted following neutron irradiation at ~350°C to 30dpa. There was no significant degradation of proportional limit stress (PLS) and ultimate flexural strength as shown in Figure 3. This result is contrasted with that of SiC composite with same matrix but with different fiber (Hi-Nicalon Type S: HNS) and interphase (multilayer PyC) exhibiting significant mechanical property degradation following irradiation at similar neutron dose and temperature. The findings of this study will be useful to design radiation-resistant SiC composite materials. (T.Koyanagi, Y.Katoh)

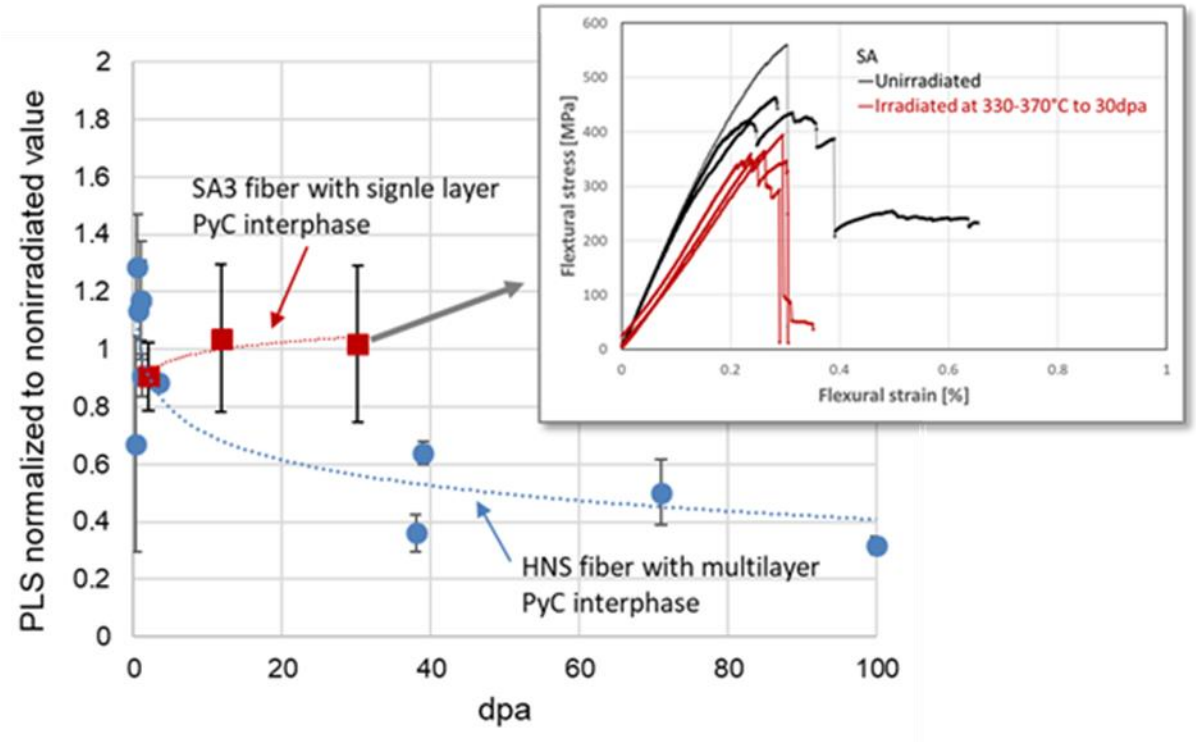

Figure 3. Proportional limit stress of two types of SiC composites as a function of displacement damage level.

- **[INL]** TerraPower approval was obtained to use the Pressure Resistance Weld (PRW) system at MFC for this ODS cladding joining project. The ORNL collaborator was contacted for ODS cladding sample geometry. A good quantity material of PM2000 was located with composition similar to MA956 to be used for testing of PRW for ODS-FeCrAl. The electrode for PRW was redesigned for this project use. (J. Gan)

LWR Irradiation Testing & PIE Techniques

- **[INL]** Ninety one effective full power days of irradiation of ATF-2 were completed, and experiment requirements established for the ATF-2 design change during ATR cycle outages 166B (addition of 6-pin holders with BWR-diameter pins at Tiers 3 and 4) and 168A (addition of a 9-pin holder with wireless instrumentation at Tier 5/6). (G. Hoggard)
- **[INL]** The project competed fabrication of another set of flux-wire monitors and started preparations for the next planned shipment of irradiated capsules in the spring. (C. Murdock)
- **[INL]** None of the current batch of FeCrAl rodlet cladding ATF-1 experiments were found to have had faulty welds during irradiation that lead to fission gas release to the capsule plenum. All rodlets were removed from their capsules successfully. Visual examinations were performed on all the rodlets from ATF-06 (UO2-FeCrAl), ATF-08 (UO2-FeCrAl), ATF-44 (U3Si5-FeCrAl) and ATF-73 (UO2-FeCrAl diffusion couples). No anomalous features were observed on the cladding. (J. Harp)

LWR Fuel Safety Testing

- **[INL]** Conceptual design efforts are on-going for Super SERTTA. The TREAT Water Experiment Recirculation Loop (TWERL) design team was assembled and conceptual design activities were initiated. (H. Guymon)
- **[INL]** The first sample of high-burnup fuel was harvested from North Anna fuel, mounted, encapsulated, and shipped to oxidation furnace in order to release and capture fission gas from sample. Initial work for hydriding zirconium was started. Literature research and partial pressure methods were initiated for future PCMI test development. (L. Emerson)

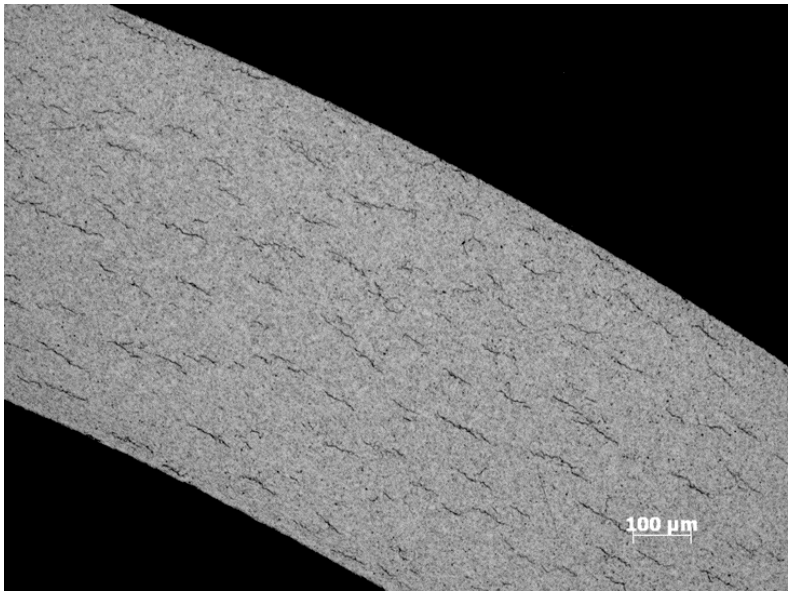

Figure 4. Initial attempt at pre-hydriding zircaloy using sealed partial pressure method.

- **[INL]** A method was established and preliminary investigations conducted of infrared thermometry under water. The pyrometer and self-powered neutron detectors showed excellent performance in support of the ATF SETH B experiments. The MPFD was inserted into TREAT for continued evaluation of sensor performance in TREAT environment. (K. Bowman)
- **[INL]** ATF-SETH Transient runs and data analysis continued. Temperature data continues to be as expected after the initial transient troubleshooting effort. The ability to obtain meaningful data from transient runs is vitally important. (D. Dempsey)
- **[INL]** Aqua-SETH analysis was completed and moved into final eCR review and approval. Fabrication of the rodlet is on schedule and should complete in the second week of December. Irradiation of this fueled rodlet will provide important input to the MARCH-SERTTA experiment design. (D. Dempsey)
- **[INL]** Hodoscope activities in support of the TREAT experiment program for SETH-B transient testing are on-going, including transient operations with the Nuclear Equivalent Device (NED). Development of a Fuel Motion Monitoring System (FMMS) process flow and data package template to support experiments was initiated. (H. Guymon)

LWR Computational Analysis & Fuel Modeling

- **[ORNL]** Recent effort in fuel performance modeling has focused on development of capabilities to simulate coated cladding using BISON. While comprehensive models have not been developed for specific coatings, current work uses zirconium-oxide properties to test the code convergence with the discrete meshed layer on the outside of the cladding. Because of the large aspect ratio of the individual finite elements in the coating (sometimes as high as 200), it is imperative to determine the sensitivity of the code results to the mesh density in the coating. Ongoing work is being performed to determine the optimal handling of the coating layer by performing a mesh sensitivity analysis. This will ensure that the mesh density is fine enough to get accurate results without becoming too computationally taxing. Effort is also ongoing to establish the neutron and thermal-hydraulic boundary conditions for further assessment of SiC composite BWR channel box performance. (B. Wirth)

Industry FOA

- **[INL]** The packaging of the uranium silicide fuel pellets was completed. The packaged fuel pellets were loaded in the shipping drum. The fuel pellets were shipped to Westinghouse. This project is complete with the exception of the FY-19 project closeout activities to ensure all files are finalized on the project server. (S. Martinson)
- **[ORNL]** The third batch of BWR geometry C26M2 tubes (approx. length ~34 feet, heat #17025001, drawn at Century Tubes, Inc., San Diego, CA) was shipped back to Century for additional annealing. After annealing, the tubes are to be delivered to GRC, Wilmington, NC, for a weld study. (Y. Yamamoto)

ADVANCED REACTOR FUELS

AR Fuels

- **[INL]** During FY18 a series of experiments was performed to quantify americium volatilization at different pressures as reported in “Americium Volatility Study”. During these experiments, analytical samples were taken and submitted to for chemical analysis. The results are shown in Table 1 below. As seen, a loss of americium content was seen in the first run, however, this corresponds to a gain in the Y2O3 crucible liner mass. This correspondence suggests that the americium loss seen after Run 1

is due to chemical interaction with the liner, not volatilization. This provides further support for the conclusions drawn in the report that americium losses can be controlled with a modest amount of over pressure.

Table 1: Summary of analytical results following Am experiments

Specie	Run 1	Run 2	Run 3	Run 4
234U	19.1	17.4	17.7	17.9
235U	2050	2080	2120	2130
236U	95.9	88.8	90.8	91.2
238U	912000	910000	938000	930000
239Pu	66500	57000	59100	58300
240Pu	13200	11200	11600	11600
241M/Z	23100	15700	16200	6180
ΔLiner*	0.044 g	0.044 g	0.068 g	-o.109 g

* Liner mass was taken before and after each run

In the area of extrusion, the extruded billet made up of 6 individual U-10Zr segments was further characterized. As part of this characterization, four sections approximately 10 in. (250 mm) in length were sectioned axially and polished. No segment interfaces were visible in these sections. Figure 5 below shows two of the sections, one from the oxidized segment interface region and one from the as machined segment interface region. Some porosity was visible, however, further characterization is necessary to determine if these were caused by the interface or during the sectioning process performed on a mill. Characterization activities also continued on the annular extruded billet. It was discovered that the mandrel which broke during extrusion broke into several pieces versus two. The mandrel/U-10Zr interface will be further characterized. (R. Fielding)

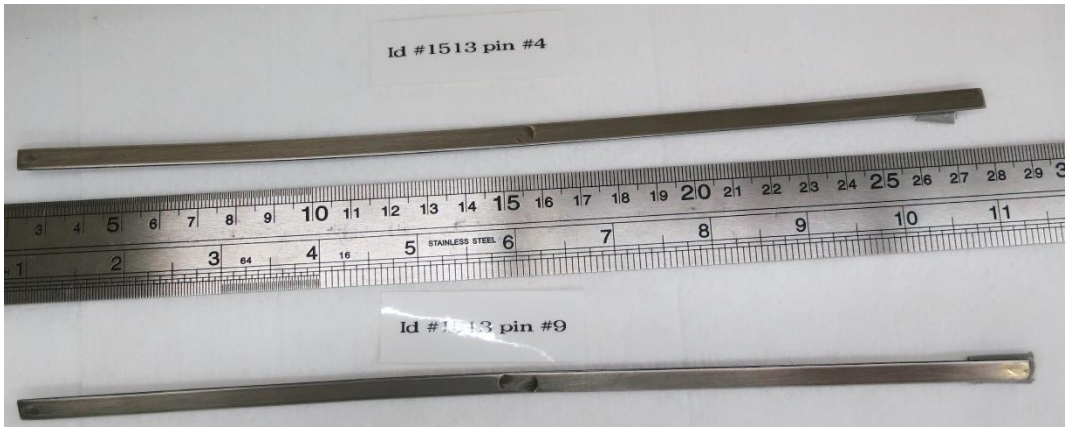

Figure 5. Segmented extruded rod axial sections. Pin #4 was from the oxidized segment interface section.

- **[INL]** As part of the FAST test design, additional cladding will need to be produced. The specification for the cladding has been written and approved and submitted for contract review. The contract review process is complete, and procurement has been initiated. Hardware design input also continues in the area of endplug designs. Based on consultations with the machine shop, the original plug design was modified slightly to increase weldability and ease of fabrication. These plugs welded although some detrimental aspects were noted. The design was slightly modified again to reduce the

volume of rodlet material above the endplug. Welding trials using these endplugs will begin in December. Figure 6 below shows the 1/3 diameter (0.065") trial endplug. (R. Fielding)

Figure 6. 1/3 diameter (0.065") trial endplug

- **[INL]** Dr. Dawn Janney submitted a manuscript titled. "A critical review of the experimentally known properties of U-Pu-Zr alloys. Part 2: Thermal and Mechanical Properties," to the journal Nuclear Technology. (J. Giglio)

AR Core Materials

- **[LANL]** Shear punch testing was completed on TEM disks for HT-9 and 14YWT at room temperature after irradiation to 14-35 dpa at temperatures from 378 to 524C. Data shows strong hardening in HT-9 at 425 and 378C and slight hardening in 14YWT. Data was pulled together in a report to meet a level 3 milestone. (T. Saleh)
- **[PNNL]** Effort continued focused on completing barrier hardening analyses in support of milestone M3FT-19PN020302025 titled, "Report on and Perform Neutron Irradiated Material Microstructure Analysis and Barrier Hardening Coefficient Determination (FY17)." A draft of this report was completed in late November, and the final report will be provided on or before the due date. (M. Toloczko)
- **[PNNL]** A subcontract was started with Texas A&M University to cover the costs to ion irradiated T91 in support of milestone M4FT-19PN020302026 titled, "Issue Report on High Dose Ion Irradiations on 9Cr Tempered F-M Steel (FY16)." (M. Toloczko)
- **[PNNL]** Specimen preparation was performed in support of milestone M3FT-19PN020302024 titled, "Analyze Accelerator-to-Accelerator Differences in Induced Radiation Effects and Write Report." (M. Toloczko)
- **[PNNL]** The newly produced fracture toughness (KJQ) data for HT-9 steels was further analyzed to assess the property improvement of the steels by new thermomechanical treatments (TMTs). The KJQ data for two HT-9 steels after the new TMTs consisting of rapid quenching and single or double step tempering were integrated with the existing fracture toughness database for ferritic-martensitic steels (FMSs) and nanostructured ferritic alloys (NFAs). While the mechanical properties of HT-9 steels varied widely with their processing routes, the TMTs consisting of a rapid water quenching and a reduced degree of tempering at 500°C or 600°C yielded the best combinations of excellent strength and high fracture toughness, which are comparable to those of NFAs. (T.S. Byun)

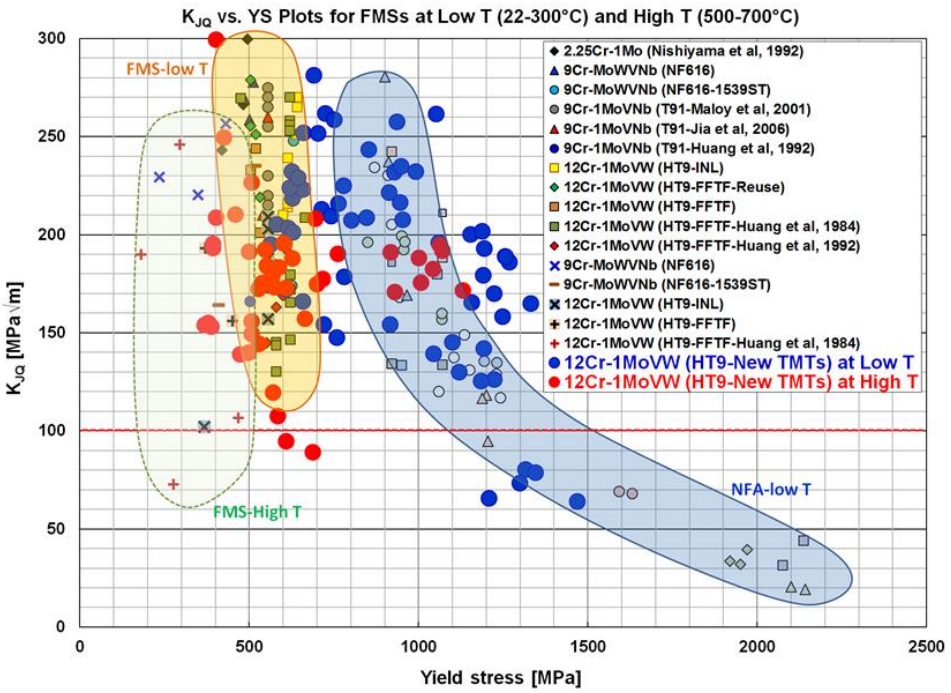

Figure 7. K_{JQ} vs. YS Plots for FMS in Low Temperature Range (22-300°C) and High Temperature Range (500-700°C).

- **[PNNL]** Funding for FY-19 has just arrived at PNNL. Last fiscal year, as part of the program to advance the technology associated with fabricating tubing from difficult-to-fabricate materials, the PNNL rolling mill was 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. The rolling mill with pilger dies installed and ready for startup testing is shown in Figure 8 below. The initial startup pilgering run was completed last fiscal year with two passes performed successfully. With the arrival of FY-19 funding, the pilger setup is being readied for subsequent passes which will take the tubing down to final dimensions. The startup runs were performed with stainless steel so as not to risk the more limited supply of MA956 for 14YWT unduly. After the startup testing with stainless steel is complete, MA956 and 14YWT will be pilgered. (R. Omberg)

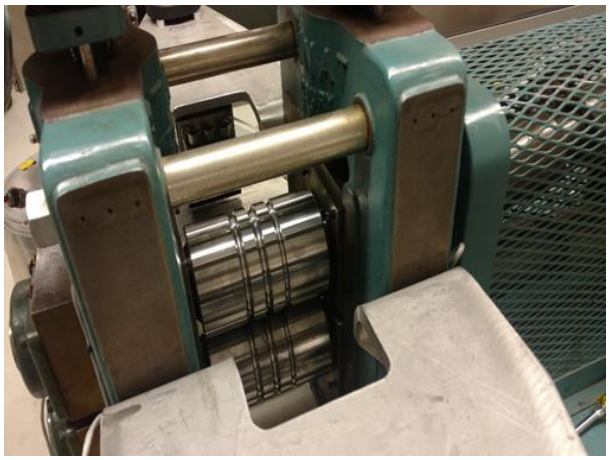

Figure 8. Pilger mill with roller dies installed ready for startup testing.

- **[ORNL]** Ten ball milling runs, each consisting of 1 kg of OFRAC powder, were completed using the high kinetic energy CM08 Simoloyer. Five 4-in. diameter cans fabricated from 4140 steel and the 10 kg of ball milled OFRAC powder were submitted to the processing group for initiating the canning and degassing stages. The cans will be extruded through a 1.75 inch diameter die to form rods. The goal of this task is to produce 5 master rods that will be shipped to NFD (Nippon Nuclear Fuel Development) for fabricating tubing with final dimensions of 6 mm outer diameter and 0.5 mm wall thickness. (D. Hoelzer)
- **[ORNL]** Transmission electron microscopy analysis was conducted on the specimen (Y01) of 14YWT (SM13) that had been neutron irradiated to 16.6 dpa at ~386ºC at BOR60. The Y01 specimen was lifted from a neutron irradiated TEM disk and thinned by focus ion beam (FIB) using the FEI Versa 3D Dual Beam FIB-SEM located in the LAMDA facility. Bright-field through-focus images obtained from multiple areas in the microstructure of the Y01 specimen did not reveal cavities or dislocation loops. Several Fe M-jump ratio and Ti M-jump ratio maps were obtained using energy-filtered TEM to reveal the dispersion of oxide-nanoclusters and possibly the Cr-rich a' particles, but the specimen thickness was ~20-25 nm too thick for obtaining the best resolution for imaging these nano-size features. However, the Atom Probe Tomography results obtained by Dr. M. Auger at Oxford University, UK confirmed the presence of both the nanoclusters and a' particles in the equivalent FIB specimen (Y01) of 14YWT. Support for the specimen preparation and TEM analysis was provided by the NSUF Rapid Turnaround Experiment: 18-1130 (P.I.'s: Dr. M. Auger, Oxford University and D.T. Hoelzer, ORNL). These results highlight the effects of neutron irradiation on the microstructural stability of 14YWT and the capabilities of advanced instruments in LAMDA for obtaining high impact PIE results. (D. Hoelzer)

AR Irradiation Testing & PIE Techniques

- **[INL]** FAST mechanical drawings are completed and various Preliminary Design analyses and Fabrication Development activities are in process. (C. Murdock)
- **[INL]** Relevant recent MOX work was presented at the US-Japan CNWG meeting in Los Alamos, New Mexico. Chemical analysis of samples from EBR-II irradiated minor actinide ternary fuel (X-501 G591) was initiated. Fission Gas Release measurements were performed on two historically irradiated pins from EBR-II. Fission gas release was in-line with expectations. These pins will be used to perform contemporary analysis of the irradiated fuel microstructure. Samples were selected and prepared for electron microscopy later this fiscal year. (J. Harp)
- **[INL]** The Functional and Operations requirements for the hot cell furnace testing were transferred to the hot-cell engineering department. (J. Harp)
- **[ANL]** A journal paper was developed summarizing the annular fuel performance in a high-burnup sodium cooled fast reactor. A series of key fuel performance parameters, such as peak fuel temperature, reduction of fuel central void, and cumulative damage fraction of the cladding, were predicted using BISON code for both upper and lower plenum configurations. The paper concludes that annular fuel design with a lower smeared density is capable of accommodating the significant swelling of metallic fuel at high burnup. Meanwhile, the adoption of a lower plenum configuration effectively lowers the gas pressure inside the HT9 cladding and reducing the creep damage accumulation. (T. Kim)

AR Fuel Safety Testing

- **[INL]** Communication was established and a multi-day meeting held with TerraPower in order to initiate a MK-IV liquid metal test loop for TREAT. Scoping and capabilities for both INL and TerraPower were established in order to support the development of a project plan. (L. Emerson)

- **[INL]** Design activities are on-going to support the final design of the TREAT Characterization-scale Instrumented Neutron Dose Irradiation (CINDI) experiment schedule for irradiation in March of 2019. CINDI final design kick-off meeting is scheduled in January of 2019. A draft Focus Area Test plan in support of the fuel safety research milestone was initiated. (H. Guymon)
- **[INL]** Work continued to establish contacts and gather input from stakeholders for the international joint project transient test plan. Modeling personnel were established for the BISON metal fuel transient benchmark modeling tasks. (L. Emerson)

AR Computational Analysis & Fuel Modeling

- **[INL]** BISON modeling of U10Zr spherepack fuel indicates that creep and swelling of the fuel particles during irradiation will result in dramatic enhancement of the thermal contact between the fuel particles and elimination of the void volume in the particle bed. This is a favorable result that reinforces the motivation for the proposed U10Zr spherepack fuel testing by the AFC. Figure 9 shows transformation of a U10Zr spherepack fuel particle during radiation. Body centered cubic particle packing order explains the resulting geometry. (P. Medvedev)

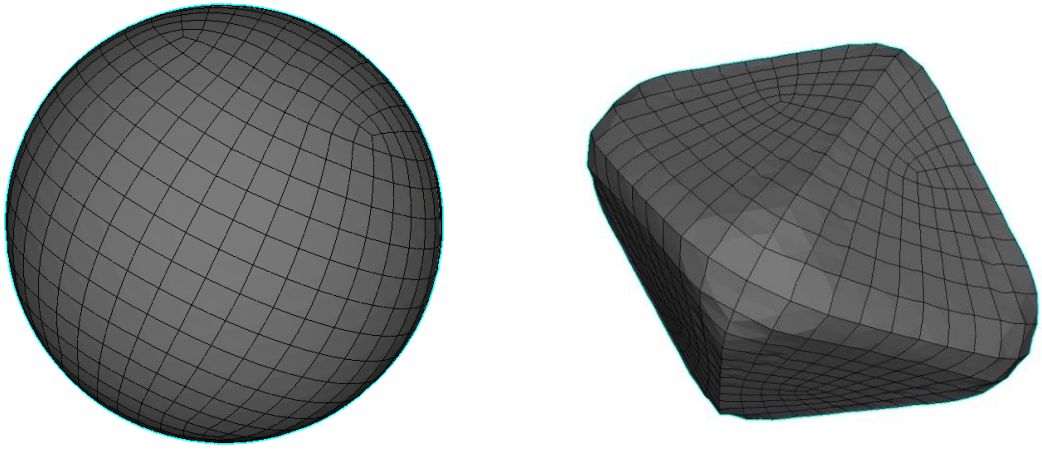

Figure 9. Transformation of U10Zr spherepack fuel particle during radiation

CAPABILITY DEVELOPMENT

CX Fuels

- **[INL]** Preparations for installation of the TCM at the IMCL are ongoing. Meetings with IMCL personnel to provide work control documentation have been held. Training requirements for IRC personnel have been identified. A walk down of the unloading and placement of the TCM at IMCL has been performed with IMCL personnel. Preparation of the TCM for transport has been initiated, and transport of the TCM to the IMCL will begin on December 10. (S. Martinson)
- **[INL]** Work is continuing on Photothermal Radiometry development. Work during the past month has focused on modeling the effects of diffraction so they can be accounted for in the experimental results. (D. Hurley)

TREAT Testing Infrastructure

- **[INL]** Design of the potential shielded cell in building MFC-723 in support of TREAT experiments was initiated. Design and equipment identification to establish TREAT experiment handling capabilities at MFC are on-going. (H. Guymon)

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

Material Recovery and Waste Forms Development

PROCESS CHEMISTRY AND INTEGRATION

- **[INL]** A manuscript titled, "Influence of Pre-organized N-Donor Group on the Coordination of Trivalent Actinides and Lanthanides by Aminopolycarboxylate Complexant," was accepted for publication in Chemistry – The European Journal (Latest ISI Impact Factor: 5.16). The article discusses the introduction of N-methylpicolinate substrate into the metal coordination pocket of new complexant from the aminopolycarboxylate family. Studies of trivalent f-element complexation revealed the reagent as best option for f-element sequestration and actinide/lanthanide differentiation in aqueous environment of unprecedented acidity. The full article citation is below. (J. Law)
  - Heathman, C.R.; Grimes, T.S.; Jansone-Popova, Roy, Santanu; Bryantsev, V.S.; Zalupski, P.R. "Influence of Pre-organized N-Donor Group on the Coordination of Trivalent Actinides and Lanthanides by Aminopolycarboxylate Complexant." Chem. Eur. J. 10.1002/chem.201804723.

- **[ONRL]** Density functional theory (DFT) calculations were performed in support of the effort to develop new polyaminocarboxylc complexants for selective binding of minor actinides in aqueous solution. The work was focused on predicting Am(III)/Eu(III) selectivity for a new DTPA derivative (DTTA-PzM), in which one of the five carboxyl groups in a molecule is replaced by a pyrazine group. The results show that while DFT calculations predict that DTTA-PzM ligand is less selective for Am(III) than the pyridine-based analogue, the absolute values are significantly underestimated compared to the experimental results. Based on the natural bond orbital theory applied to DFT density we conclude that the main difference in binding of Am (III) and Eu(III) lies in the ability of 5f electrons to participate in back donation to ligand empty orbitals, while the participation of 4f electrons in back donation is minimal. The next step will be to apply more advanced electronic structure methods to better reproduce the experimental results and better understand the origin of selectivity. (S. Jansone-Popova)
- **[ANL]** Waste from work conducted during FY18 awaits pick-up by waste management, now expected to occur in December. (W. Ebert)

WASTE FORM DEVELOPMENT AND PERFORMANCE

Electrochemical Waste Forms

- **[ANL]** A journal paper summarizing the results of tests with prototype iron phosphate waste form materials for dehalogenated EChem waste salt is being drafted. Tests with an improved material being made at PNNL are expected to begin in early 2019. (W. Ebert)

Glass Ceramics Waste Forms

- **[PNNL]** The paper titled "Kinetics of Oxyapatite [Ca2Nd8(SiO4)6O2] and Powellite [(Ca,Sr,Ba)MoO4] Dissolution in Glass-Ceramic Nuclear Waste Forms in Acidic, Neutral, and Alkaline Conditions," completed for milestone M3NT-18PN030105071, was revised to address minor reviewer comments and resubmitted. The paper is expected to be accepted for publication soon. (J. Crum)
- **[ANL]** Preparation of glass for modified PCTs has been delayed due to a broken mill, for which replacement parts have been ordered. Other equipment has been prepared and the test matrix has been developed. (W. Ebert)

- **[PNNL]** A series of ideas to test the structural relaxation of gels has been identified and are in the planning process. The idea that the gel restructuring is critical to glass corrosion is a new one and testing is needed to help evaluate both the potential of the mechanism and the way it can be modeled. (J. Ryan)
- **[SRNL]** SRNL performed two tests with the CIM using surrogate glass ceramic feed. Of the two tests, one contained 1kg of feed to flush the melter of previously processed ceramic material. A second test with 1.3 kg was performed to assess operation of CIM in preparation for larger-scale test. Estimates of pour rates and melter operation were gathered during these tests. A test using a pan with the canister diameter to assess flowing during processing is scheduled for early December. (J. Amoroso, P. Smith)
- **[SRNL]** SRNL attended and presented research at ANS Winter Meeting and Nuclear Technology Expo held in Orlando, Florida on November 11-15, 2018. (J. Amoroso, P. Smith)

Iodine Waste Forms

- **[ANL]** The report summarizing the approach for testing iodide waste forms is being drafted to meet an end of January milestone. Electrochemical testing with AgI is being completed prior to tests with HIPed materials provided by ORNL. (W. Ebert)
- **[PNNL]** An oral presentation was given on "Durability of Iodine Containing Waste Forms" at the Scientific Basis for Nuclear Waste Management Symposium at MRS2018 in Boston, MA on November 29th. (M. Asmussen)

Domestic Electrochemical Processing

- **[ANL]** Equipment and test materials have been obtained and are being assembled for tests to study Zr behavior in molten salt and design reviews were held. Specimens from tests conducted during FY18 were submitted for analysis. (W. Ebert)

SIGMA TEAM FOR OFF-GAS

- **[ORNL]** A report titled, "Design and test an Off-Gas Capture System for Advanced Tritium Pretreatment," was completed to fulfil the Level 4 milestone M4FT-19OR030107022, titled "Complete the design of, and prepare test plan for, the NOx tritium pretreatment off-gas system for I and H-3 capture," on schedule. All technical reviews of this milestone report have been completed and it is awaiting release by Export Control and final management review. The following is a summary of the report. (B. Jubin)
  - The use of NO_2 as the oxidant in an advanced tritium pretreatment (ATPT) allow the oxidation to be performed at lower temperatures and may result in the quantitative release of iodine from the fuel. The ATPT off-gas will contain up to 75 vol% NO_2 gas. An initial series of tests were conducted in fiscal years 2017–2018 with the intent of demonstrating the recovery of iodine and tritium using these sorbents from a recirculating gas stream that simulated the NO_2 recycle loop envisioned for the ATPT system. These initial tests showed low tritium recoveries and significant variations in the iodine recovery on the gA. Ultimately it was concluded, following disassembly of the system, that corrosion within the system was at least partially the cause of the poor recovery for both species of interest. All components of that system were disposed of at the end of the analysis. One of the conclusions drawn from those tests pointed to the reconsideration of the materials of construction. Based on that recommendation, a new system has been designed that will use high nickel alloys wherever possible, a redesigned surge tank and feed system and a more modular system design that will support testing of the system with incremental increases in complexity to allow the isolation of any element that results in changes to recovery of target

species. A multifaceted test plan has been developed for the test system that includes a total of 15 tests and a total of 27 individual runs.

- **[ORNL]** The report for the Level 3 milestone M3FT-19OR0301070225, titled, "Quantify the potential physisorption on silver based sorbents that was potentially observed in FY 17 VOG testing," was completed on schedule. All technical reviews of this milestone report have been completed and it is awaiting release by Export Control and final management review. The following is a summary of the report. (B. Jubin)
  - This study evaluated the effect that sample removal procedures, specifically vacuum removal, may have on the measured iodine content of the sorbent. If sample removal procedures are biasing the measured iodine content of the loaded sorbent, this could explain the incomplete mass balance observed in previous testing. A total of five tests were conducted in which Ag^0Z was contacted with either an I_2- or CH_3I-bearing humid gas stream ($[I_2]$ = 100 ppb; $[CH_3I]$ = 200 ppb) for a loading duration of 18 days. The sorbent material was sampled using two different methods, and the iodine loadings for each removal method (vacuum and pouring) were compared. Tests 1–3 were observed to have iodine loadings near or below the detection limit of the analysis. These results led to system adjustments before completion of Tests 4 and 5. Tests 4 and 5 showed quantifiable recoveries of iodine on the sorbent and were used to evaluate the effects of the sample removal method on the measured iodine content of Ag^0Z challenged with CH_3I. These later tests showed that no quantifiable amount of adsorbed iodine (fed as CH_3I) was removed by vacuum during sampling when Ag^0Z is not saturated. None of the analyzed bed segments displayed variation in total iodine loading as a result of vacuum retrieval. Previously reported testing also indicated that vacuum removal does not affect adsorbed iodine on Ag^0Z when it is fed as elemental iodine (I_2). These results indicate that the incomplete recovery of iodine on silver-based sorbent beds previously observed by the authors is not an artifact of the sample removal method.

- **[ORNL]** A report summarizing production of four large-format HIPed I–AgZ samples has been completed and will be issued shortly. These samples are 1.5 in. diameter and 2 in. length and contain 49 g of I–AgZ. Two samples were prepared at an iodine loading of 64 mg I/g I-AgZ, and two samples were prepared at an iodine loading of 135 mg I/g I–AgZ. These two sets of duplicate samples will be made available upon request in support of iodine waste form durability method development efforts. This is a FY18 carry-over task. (B. Jubin)
- **[ORNL]** In FY18 the effects of NO and NO2 on methyl iodide and iodine adsorption onto AgZ were studied using a statistically designed test matrix. Efforts in FY19 will complete this work to determine the effects of NO and NO2 on I2 and CH3I adsorption onto silver-functionalized aerogel. The first tests conducted using aerogel as the CH3I sorbent did not show any CH3I loading onto the sorbent. As part of the troubleshooting process, the CH3I system has been modified to eliminate unnecessary carrier gas and has removed several check valves that were inhibiting flow to TGA manifold, and the gas pressures of the various streams were rebalanced.
- **[ORNL]** In the month of November, the Milestone Report (M3NT-18OR030102042) describing the "system performance evaluations for the concentration of tritiated water with advanced LTA zeolite membranes," was completed and routed through ORNL RESolution system for technical review and approvals. The anticipated date of release for distribution is December. (B. Jubin)

FLOWSHEET DEMONSTRATIONS

- **[ORNL]** Bill Del Cul and Emory Collins, along with other members of the review committee [Candido Pereira (ANL) and John Vienna (PNNL)], met at INL during November for the first review

committee meeting and MRPP facility tour with the newly formed INL operations team. The pilot plant is a relatively large (quarter-scale, multi-kilogram) batch-operated facility with key equipment constructed of corrosion-resistant, Hastelloy C, built for the recovery of HEU from spent navy fuel, and potentially, spent ATR fuel, by means of the dry hydrochlorination process. There are both similarities and differences of the chlorination process and equipment used over the last few years at ORNL for RD&D of the process for recovery of zirconium from commercial spent fuel cladding, as a means of HLW reduction and potential recycle of hafnium-free zirconium. Some of these were discussed at the meeting. (B. Jubin)

- **[INL]** INL hosted a technical review in November, with members from INL, PNNL, ORNL and ANL, to initiate work on the ZIRCEX Demonstration. The demonstration will integrate results from the hydrochlorination process in INL's Material Recovery Pilot Plant (MRPP) with uranium solvent extraction and vitrification units into a single integrated uranium recovery demonstration. Next steps are development of flowsheets for the solvent extraction and vitrification units, and a recommendation for a single facility at INTEC to house the demonstration. An analysis of alternatives to identify the best facility is underway. (M. Patterson)

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

MPACT Campaign

MANAGEMENT AND INTEGRATION

NTD & Technical Support

- **[LANL]** MPACT Federal Program Manager, CAM, and NTD held an Advanced Fuel Cycle Scoping Review Panel call on November 20th, 2018. The call developed next steps for coordinating MSR safeguards activities. Jeff Sanders (INL) was recognized at the ANS winter meeting for his sustained MPACT efforts to support Safeguards and Nuclear Material Accountancy research.

ADVANCED FUEL CYCLE SCOPING

Advanced Process Modeling and Simulation (Process Tests)

- **[PNNL]** Continued to identify source material for LANL's MicroCal analysis efforts. A varied inventory of unique radioactive materials has been identified and could be loaned and/or committed to LANL as per their receiving requirements. Samples of North Anna sister rods, ATM-109 spent fuel, and dissolved HEU samples are examples of materials that could be prepared for analysis.

Advanced Fuel Cycle Scoping – Review Panel

- **[ANL]** Participated in teleconference discussion regarding molten salt reactor safeguards needs.
- **[LANL]** Participated in the MPACT Advanced Fuel Cycle Scoping teleconference where we discussed the current status of technologies and next steps going forward.

SAFEGUARDS AND SECURITY BY DESIGN – ECHEM

Microfluidic Sampler

- **[ANL]** Acrylic prototypes of the molten salt centrifugal pump were tested by submerging them in water and measuring the total head produced (the maximum height the output can be pumped above the water level). After iterating impeller geometries, a final design was chosen and the motor speed required to produce the required flow rate and head (1 liter per hour at 3 feet) was found to be 1800 RPM. The final technical drawings for the pump are currently being generated and fabrication of the pump is expected to begin this month. Fabrication of the stainless steel droplet generator system was completed via additive manufacturing through a vendor.

Actinide Sensor

- **[INL]** Qualification to work in the Fuel Cycle Glovebox (FCG) is still ongoing. New procedures have been written to work in the FCG. Surrogate work with GdCl3 continued in the Engineering Development Lab (EDL). Experiments were performed to evaluate two different ion exchange techniques to minimize the possible tiny or micro-cracks resulting from the stress from the shrinkage of the salt during cooling when exchanging sensor tubes.

Bubbler for Measuring Density and Depth of Molten Salt

- **[INL]** The bubbler was completely dried and assembled. Dry testing commenced in late November after the area where the bubbler was located was cleared for access. The purpose of the dry testing is to determine pressure drop offsets for the milestone prior to putting the bubbler back into the electrorefiner (ER). The bubbler will be put back into the ER following the dry tests.

ER Voltammetry

- **[ANL]** Progress is still being made toward the automation of the voltammetry analysis to provide near real-time output of data from the sensor. Testing of the automated scripting that has been created is expected to begin shortly. Design work for a sensor design that is suitable for installation in the IRT electrorefiner at INL has also been begun.

MODELING ADVANCED INTEGRATION AND MILESTONE 2020:

Advanced Integration (Safeguards Facility Models)

- **[ANL]** AMPYRE code has been updated to account for post-processing material transfers following each unit operation. Implementation allows for a time delay following the "run" method of each "unit", which can be used to represent a variety of plant operations. This post-processing time span can be set independently for each unit operation and can be used to represent time during which products of the unit are transferred to the physical location of the next unit. It can also represent when the unit is not processing but it otherwise unavailable to restart. For example, a post-processing hold time when salt is drained from electrorefiner products or when confirmatory measurements are being performed. In support of the microcalorimeter measurement campaign, samples were identified that may be of interest. These were produced from aqueous reprocessing experiments with spent fuel performed at Argonne (UREX+ demonstration) and have accompanying ICPMS and TIMS data for comparison with microcalorimetry results.

Advanced Integration (Methods)

- **[LANL]** Wrapped up statistical simulations with Voltammetry data.

Advanced Integration (Security Facility Models)

- **[SNL]** The physical security model for the building is nearing completion, and work is now focusing on developing the site layout in more detail. We are targeting completion of the models by the end of January in order to have time to run analyses before the May milestone.

EXPLORATORY RESEARCH / FIELD TESTS

Microcalorimetry

- **[LANL]** Measurements have continued on LANL Pu items including MOX. We are now beginning the first quantitative isotopic analysis with data from the new instrument architecture. We are able to routinely achieve statistical uncertainty of ~0.1% on major peak ratios. Experience has shown that at high dose rates, the frequency of superconducting resonators used for multiplexed readout can shift and degrade performance. In response, we have installed shielding inside the cryostat to reduce dose rates at the resonator chips. Testing is underway. We have started specifying and ordering components for the field testing instrument. In particular, heat load calculations indicate that a much smaller pulse tube refrigerator (Cryomech PT403) can be used. This requires only single-phase 220V power, which is readily available in almost any building. We are continuing to coordinate with other DOE laboratories about items to measure in the end-user assessment. We have identified priority samples from pyroprocessing at INL and the UREX+3a aqueous processing at ANL. We are also in discussions about possible measurements on samples from the IAEA and LLNL.

For more information on MPACT contact Mike Browne at (505) 665-5056.

Systems Analysis and Integration (SA&I) Campaign

CAMPAIGN MANAGEMENT

- **[ANL, BNL, INL, LLNL, ORNL, PNNL, SNL]** Completed a BCP to reflect the reduction in the previously established FY19 funding for the campaign.

EQUILIBRIUM SYSTEM PERFORMANCE (ESP)

Performance of Fuel Cycle Systems

- **[ANL]** Hosted a panel session, entitled "Micro reactor concepts for special purpose application", at the ANS winter meeting, Orlando, FL., November 14, 2018. The forum was useful for collecting information on the micro reactor concepts that are under development by industry and national labs.
- **[ORNL]** A set of standard CANDU spent fuel isotopics were generated using the ORIGEN library for a 37-element fuel bundle for analyzing the Chinese fuel cycle. The results were provided to ANL for use by the other labs in the other parts of the assessment. Ongoing work will extend this 37-element bundle to an AFCR bundle to generate the spent fuel isotopics for a DRU fuel bundle under design for the AFCR. The data available for this design is more limited and so is taking longer to create the model based on correct data. The validity of the results is also being checked against other data.
- **[INL]** The report INL/INT-18-51395 was revised based on feedbacks obtained from ANL. In particular, performed calculations of the effective delayed neutron fraction for each cycle to estimate the control rod worth when LEU assemblies are loaded in the SFR core.

Economic Analysis Capabilities and Assessments

- **[ANL]** F. Ganda participated, as an invited panelist, in a special session of "The Grand Challenge of Closing the Fuel Cycle: Federal, Commercial or Hybrid Ownership of Recycling Facility", at the ANS winter meeting in Orlando, FL., on November 14, 2018.
- **[ANL]** F. Ganda received the DOE Nuclear Energy Fuel Cycle R&D Excellence Award at the ANS winter meeting in Orlando, FL., on November 14, 2018 and also gave a presentation of "Ongoing research on Nuclear Economics for the System Analysis and Integration Campaign."
- **[ANL]** For collecting information on the Public versus Private construction cost, contacted Dr. Dave Moncton (MIT), who has involved in the APS (ANL) and SNS (ORNL) projects. Dr. Moncton mentioned the importance of "good versus inferior" project management rather than "public vs. private" construction cost comparison, and provided useful information which includes the best practices for a successful project management for large construction projects, loaded cost schedule system, and expert who has involved in mega-projects. Separately, BNL provided cost information on the SNS, which will be used as a starting point to inform on the best structures/approaches for the construction of megaprojects within the DOE framework.
- **[ANL]** A preliminary write-up was developed for the work performed on three accounts (Air, water, steam service systems; Waste treatment system; and Coolant treatment and recycle), aimed at improving the accuracy and usability of the ACCERT algorithm.
- **[ANL]** Provided the Excel and Matlab files containing the actual cost calculations used for the VTR CD0 to VTR management team (Lee Nelson, INL). Those calculations were described in detail in the report that was submitted to the VTR leadership in August 2018.

- **[PNNL]** Investigating alternative representations of electric power systems in energy models. Awaiting FY19 funding availability for additional work.
- **[INL]** Started literature review of cost overruns. This review will shed light on the current state of knowledge on the drivers of cost and schedule overruns in nuclear construction projects. To the extent possible, this work will highlight differences in cost outcomes based on projects build by government versus projects built by private industry.
- **[INL]** Provided review and comments for upcoming report "Economic Analysis of Alternative Transition Pathways to Improve Economic Considerations in Fuel Cycle Transition".

Daily Market Studies of Advanced Nuclear Energy Systems

- **[ANL, BNL, INL, PNNL, ORNL]** Held multi-lab monthly videoconference to discuss progress in the ESP "Energy Market Analysis" activity.
- **[ANL]** Updated EDGAR code to display the total electricity cost breakdown, which provides insight into which penalties are associated with the scenario investigated.
- **[SNL]** We finished updating the Fuel Cycle Options Catalog development website, which is used to input data and for other administrative tasks, from using webparts to using Java Script. It is now compliant with current standards and will not have problems with compatibility when SNL begins implementing the next version of SharePoint.

Enhancements to the Cost Basis Report (CBR) Tool

- **[ANL]** The work on the improvements of the Cost Basis Report continued. A complete revision of the important D1-1 module on the fabrication cost of LEU fuel, and the integration of the write-up on the breakdown of the fabrication steps, as developed in FY18, is under way. Separately, work is underway to utilize the NASAP studies to develop a defensible basis for the cost of fabrication of contact-handled fast reactor's metallic fuel. Preliminary results indicate that the unit costs from the NASAP studies, updated to today's dollars, are in good agreement with the bottom up estimate that was developed in FY18, based on the process description of the EBR-II fuel fabrication effort. The agreement between these two separate efforts can be utilized to develop a defensible and informative basis for the cost of fabrication of contact-handled metallic fuel for module D1-6, for which currently no unit cost is available.
- **[INL]** Coordinated with F. Ganda, K. Williams and E. Hoffman on planned updates to the CBR in the current fiscal year. Completed the first phase of integrating new analysis on fuel fabrication costs into Module D. This is based on studies conducted at ORNL during the late 1970s, which were part assessments on nuclear non-proliferation. These studies applied a consistent basis, including assumptions, and approach to cost estimating.

Analysis of NES to Augment Information in Fuel Cycle Catalog

- **[ANL, BNL, INL, ORNL]** Collected PHWR and AHWR fuel cycle information to be used for developing fuel cycle data package (FCDP) on the Indian-like fuel cycle concept, which is the continuous recycle of U/Pu and Th/U233 with NU and Th feeds in both thermal and fast reactors (EG38).

Maintain/Update Campaign Analysis Tools

- **[ANL]** Met the Managing Director of Nuclear 21, at the ANS winter meeting to discuss the current status of the DANESS fuel cycle analysis code which can be used to simulate the dynamic mass-flow/inventory for time-evolving nuclear energy systems, and NPP-level and facility-level cash-flow.

Nuclear 21 will provide the DANESS code for the purpose of comparing its results with those from the SA&I campaign's system analysis codes (DYMOND, ORION, and VISION).

Campaign Special Sessions at International Topical Conference

- **[ANL]** Proposed a potential topic of the panel session, entitled "Sustainability of Nuclear Energy Systems in Future Energy Market," planned by the SA&I Campaign for the GLOBAL 2019 conference in Seattle, WA, September 2019. Approval of the panel session will be discussed during the kick-off call of the GLOBAL 2019 technical program committee on Dec. 4, 2018.

DEVELOPMENT, DEPLOYMENT AND IMPLEMENTATION ISSUES (DDII)

Technology Development Roadmap for a Continuous Recycle System Using Fast Reactors

- **[ANL, BNL, INL, LLNL]** Held regular bi-weekly calls to discuss the development of a technology development roadmap for a system involving the continuous recycling of U/TRU in sodium-cooled fast reactors. The questions for TRL 7 were developed, and review comments and recommendations were iterated within the TSRA national team.
- **[ANL]** Collected information on the technology maturation plans (TMPs) on the critical technology elements (CTEs) of sodium cooled fast reactor that have been identified under the technology and system readiness assessment (TSRA) procedure performed in FY18. The CTEs included advanced materials, electro-magnetic pump, SCO2 power conversion system, etc. The overall TMP outline of the advanced materials (in particular, Alloy 709) was developed and shared with the TSRA national team.
- **[INL]** Completing the Critical Technology Element and Technology Readiness Level analysis for the separations portion of the near-term fuel cycle example. Developing structure for maturation plan and roadmap. Assisting with extension of Technology and System Readiness Level questions to level 7.
- **[LLNL]** Iterated possibilities for expansion of the TSRA framework to consider flexibility to address changes in R&D priorities and higher-level issues.

Transition Analysis Studies

- **[ANL, INL, ORNL]** Started regular bi-weekly calls with ORNL and INL to work on Transition Analysis activities.
- **[ANL]** Engaged European counterparts in Functionality Isolation Test (FIT) Benchmarks to coordinate joint FY19 activities and kick off call.
- **[ANL]** Organizing webinar on "Visualization Tool for Comparing Energy Options" to be presented by Prof. Mark Deinert (Colorado School of Mines) to a limited audience of DOE-NE management.
- **[INL]** We have been fine-tuning a two-region transition/phase-out scenario for the NEA TRU Management benchmarking exercise. This will inform on the potential for one country to utilize used nuclear fuel from another country through its own transition to a closed fuel cycle.

Regional and Global Impacts

- **[PNNL]** Planning for FY19 work on investigating the long-term scale, timing and value of nuclear energy within the context of a comprehensive U.S. and global energy system. Awaiting FY19 funding availability to begin work.

Adaptation of OR-SAGE for NES Analysis

- **[ORNL]** Work continued to review NRC guidelines related to fuel cycle facility siting. Specifically, NUREG-1520, Standard Review Plan for Fuel Cycle Facilities License Applications, for review guidelines related to siting, has been reviewed.

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

Joint Fuel Cycle Study Activities

- Process experiments with two batches of interim LWR fuel were completed in the Integrated Recycling Test (IRT) equipment in HFEF.
- An Expert's meeting on Remote Handling and Mass Tracking was held in Daejeon, Korea, the week of November 12.
- Fabrication was initiated for payload baskets, grapples, and other tooling necessary for the retrieval of LWR fuel stored at Idaho Fuel Storage Facility. This fuel is scheduled to be shipped in May to HFEF for processing in IRT equipment.

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

AFCI-HQ Program Support

UNIVERSITY PROGRAMS

Site: University Research Alliance at West Texas A&M University in Canyon TX, and the following universities: University of Michigan, University of Tennessee, University of California at Berkeley, Texas A&M University, Vanderbilt University, University of Idaho, Oregon State University, Kansas State University, Northwestern University, University of Nevada at Las Vegas, Clemson University, Rensselaer Polytechnic Institute, Purdue University, Georgetown University, Virginia Commonwealth University, Florida International University, 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
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 Virginia
University of Wisconsin
Vanderbilt University
Virginia Commonwealth University
Washington State University

INNOVATIONS IN NUCLEAR TECHNOLOGY R&D AWARDS

Summary Report

- On November 14, seven of the 2018 Innovations Awards winners presented their research at the Innovations in Nuclear Technology R&D Awards special session at the American Nuclear Society Winter Meeting in Orlando, FL. The session was chaired by Dr. Daniel Vega, Acting Director of the Office of Materials and Chemical Technologies at the DOE Office of Nuclear Energy. Desktop awards were presented to the students, and photos were taken with Dr. Vega. Some of the other Innovations Awards winners from current and previous years attended the session, and all of the winners were honored with a celebratory dinner after the session. Dr. Vega also attended the dinner, along with other invited guests from the DOE, industry, and national laboratories.
- Seven award-winning papers were presented:

- Pronghorn: Porous Media Thermal-Hydraulics for Reactor Applications
  April Novak, University of California at Berkeley
- Application of Multiple Ion Beam Irradiation for the Study of Radiation Damage in Materials
  Stephen Taller, University of Michigan
- Mobility of Aqueous and Colloidal Neptunium Species in Field Lysimeter Experiments
  Kathryn M. Peruski, Clemson University
- Wearable Detector Device Utilizing Microstructured Semiconductor Neutron Detectors
  Taylor Ochs, Kansas State University
- Multi-Electron Processes by Neodymium Complexes Assisted by Redox-Active Ligands
  Ezra Coughlin, Purdue University
- Preliminary Reliability Analysis of Molten Salt Reactor Experiment Freeze Valves
  Brandon Chisholm, Vanderbilt University
- Efficient Capture of Perrhenate and Pertechnetate by a Mesoporous-Organic Framework and Crystallographic Examination of Binding Motifs
  Riki Drout, Northwestern University

- University Research Alliance began preparing reimbursements for the winners' travel expenses for the ANS meeting.
- University Research Alliance mailed desktop awards to the 2018 award winning students who did not attend the ANS Meeting.
- University Research Alliance began preparing materials for the 2019 Innovations Awards.
- University Research Alliance continued to improve the email distribution list in preparation for the 2019 Innovations Awards.

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