INL/EXT-19-56029

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

The INL is a U.S. Department of Energy National Laboratory
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INL/EXT-19-56029

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

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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

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

1. ADVANCED FUELS CAMPAIGN

1.1 International Collaborations

- **[LANL]** Stuart Maloy attended and presented at the SMINS-5 meeting in Kyoto, Japan, from July 8 through 11, 2019, to present on US-DOE Clad Materials Development Studies and learn of new materials development for Innovative New Reactor Systems. (S. Maloy)

1.2 Advanced LWR Fuels

1.2.1 LWR Fuels

- **[LANL]** The Level 3 Milestone M3FT-19LA020201026 titled, "Nanomechanical properties of high uranium density fuels," was completed. This report documents the results of high-temperature nanoindentation of CeO2, ThO2, UO2 and U3Si2. The elastic modulus and hardness of the four samples measured with nanoindentation from 298 to 973 K are presented and the results are compared with literature data where available. The challenges with the high-temperature nanoindentation of the UO2 and U3Si2 are discussed, and the approaches to minimize the oxidation are presented. Further demonstration of this technique will then justify extension to irradiated fuel samples. Results collected in this study are part of an ongoing effort to improve the high-temperature mechanical performance of nuclear fuels of interest in the DOE-NE AFC, to be integrated into fuel performance code. (D. Frazer and J. White)

[LANL] Eight high-density U3Si2 pellets with the correct geometry for MiniFuel testing in HFIR were shipped to ORNL. An as-built package detailing the to-date knowledge of the sintered pellets was also provided describing the known processing conditions, isotopics, microstructure, impurities, densities, and defects for each pellet. The pellets and associated irradiation plan in HFIR were designed to complement the ongoing irradiation and PIE studies in ATR and provide separate effects irradiation testing data on high uranium density nuclear fuel. (J. White)

[LANL] A manuscript titled, "Influence of boron isotope ratio on the thermal conductivity of uranium diboride (UB2) and zirconium diboride (ZrB2)," was submitted to the Journal of Nuclear Materials. This was a collaborative effort (LANL, Bangor University) to study the influence of the boron isotope ratio on the thermal conductivity of UB2 and ZrB2 through density functional theory. The modeling results were compared to experimental results and incorporation of the Callaway model was suggested as an avenue to predictions that could better represent the experimental data. Both UB2 and ZrB2 showed increased conductivities when a pure isotope of B is used. (E. Kardoulaki)

[ORNL] Disassembly of the first MiniFuel target and recovery of the fuel particles and SiC thermometry was completed at the ORNL Irradiated Fuel Examination Laboratory. This resulted in the first visual examination of fuel from the MiniFuel tests. Visual examinations show that the chemistry variations in UN tested in this target have not had a catastrophic effect on fuel behavior at this burnup. An example of these kernels is shown in Figure 1. The UN kernel coated particle fuel has also survived irradiation, as shown in Figure 2. This disassembly also demonstrated that particles could be recovered from the capsule while maintaining the identities of the particles from pre-irradiation, although the disassembly technique will be improved for future targets to increase the reliability of maintaining particle identification. This tracking allows for pre-irradiation and post-irradiation characterization comparisons of the volume and mass of the individual samples. The recovered SiC thermometry (Figure 3) will allow for the evaluation of the peak temperature during irradiation, which can be compared to the predicted temperature from simulations. This is an important step in further validating the MiniFuel irradiation vehicle design. Upcoming post-irradiation examination of the recovered particles includes gamma counting of the individual particles, x-ray tomography, burnup analysis, optical microscopy of the particles, and analysis of the SiC thermometry (J. Harp, D. Skitt, A. Le Coq, B. Morris, and K. Terrani).

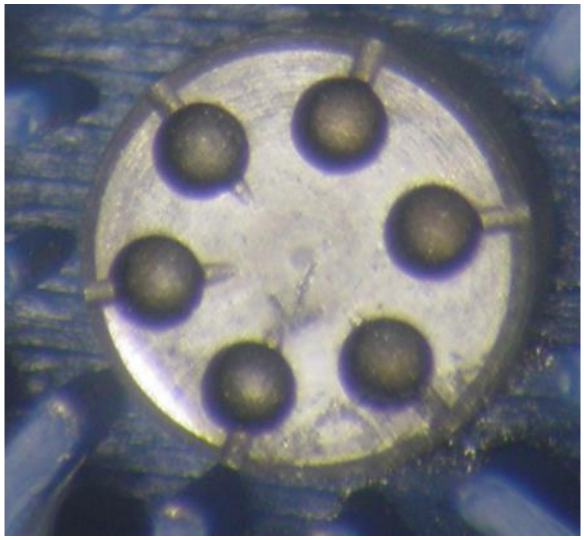


Figure 1. UC0.20N0.80 kernels from MiniFuel Target MF01, sub-capsule 221.

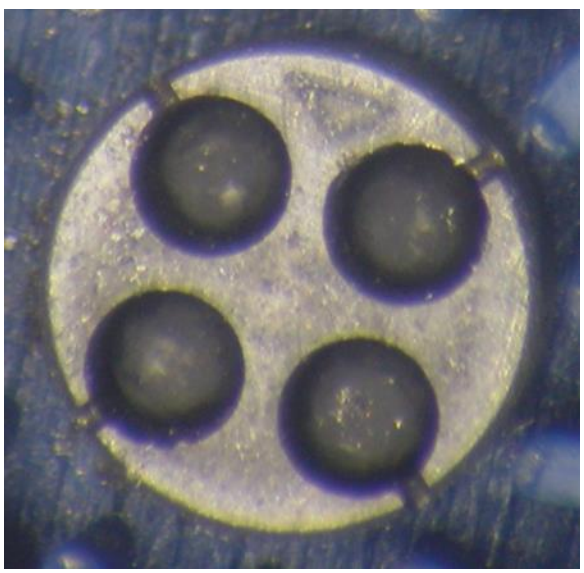


Figure 2. UC0.20N0.20 kernel TRISO particles from MiniFuel Target MF01, sub-capsule 226.

Figure 3. SiC thermometry recovered from MiniFuel Target MF01, sub-capsule 222.

1.2.2 LWR Core Materials

[LANL] Micropillar tests were performed on as-received and irradiated FeCrAl C26M alloys. Total dose was up to 16 dpa. Data was correlated with compression orientation through EBSD on samples after testing. Data was pulled together into a report to meet a Level 4 milestone. (S. Maloy)

[LANL] Characterization of tubes of C26M produced from new heats is underway to meet a milestone next month. Characterization includes EBSD analysis and nanohardness testing. (S. Maloy)

[ORNL] Property evaluation of 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 completed, including the characterization of recrystallized grain structure, tensile properties at room temperature, and ramp test up to 1450°C in a steam-containing environment. Thermal property measurements of C26M (heat #17025001, ORNL ID: C26M2), including thermal expansion co-efficient, heat capacity, and thermal diffusivity, have been completed. The results will be summarized in AFC Level 3 milestone report M3FT-19OR020202053 due on August 16, 2019. (Y. Yamamoto)

[ORNL] AFC Level 3 milestone M3FT-19OR020202052 titled, “Report on Improved Measurement of Hydrogen Diffusion in FeCrAl,” was completed in July 2019. The report summarized present efforts at ORNL to establish the capabilities for the measurement of gas permeability and diffusivity with improved resolution and repeatability. Deuterium, instead of tritium, was used in this work, based on safety and availability consideration. Our results show that deuterium permeability of the representative FeCrAl alloy (Fe-12Cr-6Al-2Mo-0.2Si-0.03Y) is close to that of model FeCrAl alloys. The activation energy of deuterium permeation increases with increasing chromium content, consistent with literature data. We also reported the dependence of grain size on deuterium transport properties. The results shown in Figure 4 indicate that the grain size has negligible impact on the gas permeability, while the sample with larger grains has larger diffusivity and lower solubility, implying that grain boundaries are more likely trapping sites for deuterium rather than quick pathways for deuterium diffusion. This work will provide basic knowledge for the development of mitigation strategies to reduce tritium permeation through FeCrAl fuel claddings. (X. Hu)

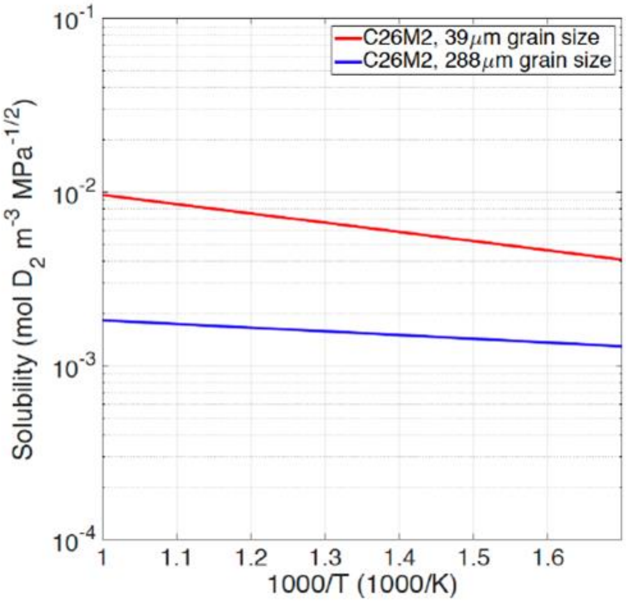


Figure 4. Temperature dependence of deuterium solubility of C26M2 samples with two different grain sizes.

[ORNL] The Level 4 milestone (M4FT-19OR020202064) titled, "Development of a Modeling Approach to Describe Thermal Conductivity of Prototype SiC/SiC Tubes for LWR Fuel Cladding," due July 25, 2019, was successfully completed. The related technical report describes the workflow and methodology to model the thermal conductivity on SiC/SiC composite tubes for LWR using the Finite Element Method. This report presents several strategies to validate, model and improve upon current models found in literature. The goal of these efforts are to establish a high fidelity modeling capability for the thermal conductivity of SiC/SiC composite cladding. A total of 16 samples were analyzed using laser flash analysis (Figure 5), XCT, and various modeling techniques. Taken together, these activities will provide important insights into the influence of microstructure of SiC/SiC composites on their corresponding thermal properties. The materials analyzed included flat coupons and round tube sections of chemical-vapor-infiltrated (CVI) SiC matrix reinforced with Hi-Nicalon Type S and Tyranno SA3 SiC fibers coated with single-layer carbon interphase. (J. David Arregui-Mena, T. Koyanagi, H. Wang, Y. Katoh)

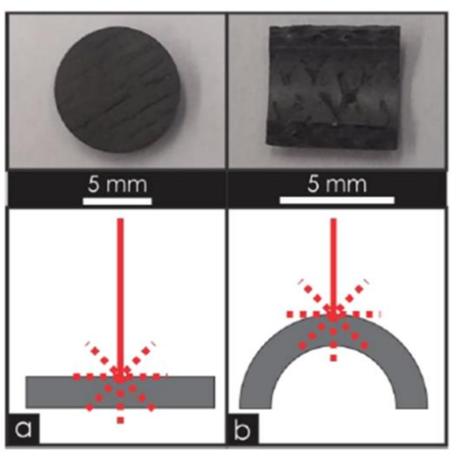


Figure 5. SiC/SiC composites methodology and geometry of specimens for thermal conductivity measurements. (a) flat specimen, (b) round section of tube.

[ORNL] A report (ORNL/SPR-2019/1211) titled, "Status Report on FeCrAl ODS Tube Production and Characterization: Insights from Annealing Studies on Ring Tensile Specimens," was completed to meet milestone M3FT-19OR020202071. This technical report provides new insights into the processing-microstructure-property relationships of the CrAZY ODS tube produced in 2018, with a strong focus on the effect of various thermal annealing treatments on alloy microstructure, ductility, and fracture properties. After annealing the as-received thin-walled CrAZY ODS tube at high temperature (900-1100°C), it was found that, although microhardness measurements and electron images confirmed the onset of partial recrystallization throughout the microstructure after annealing at >1000°C, the alloy's ductility showed no improvement unless the annealing temperature was raised even higher to 1100°C. Fracture surface images suggest that, while significant regions of unrecrystallized fine-grains exist within the microstructure, the brittle failure mode predominates. These results indicate that only a fully-recrystallized microstructure may be able to recover the ductility lost through the tube production process. A new pilger and anneal procedure has been developed based on the above results and will be applied on the tubes currently under production. (C. Massey, S. Dryepondt, M. Gussev, K. Linton)

[INL] The work based on the first batch PRW experiment and characterization results was presented at OECD-NEA 5th International Workshop on "Structural Materials for Innovative Nuclear Systems" in Japan. Additional data analysis for the first batch PRW was performed in order to identify the weld conditions for the second batch. Sample preparation for the second batch PRW has been planned. (J. Gan)

1.2.3 LWR Irradiation Testing & PIE Techniques

[INL] The ATF-2B preliminary design review for the ATF-2 Loop Testing and Redesign was completed. (G. Hoggard)

[INL] The 166A irradiations cycle has started. Preliminary design and analysis is now started for the new Framatome work scope. These capsules are anticipated to target either a 168B or 170A insertion in the ATR. ATF-18 was shipped and received at ORNL for furnace testing. Fabrication of flux-wire monitor holders continues to make progress with a target to complete by end of fiscal year. (C. Murdock)

[INL] Metallography analyses on radial cross sections from ATF-06 (UO2 fuel and Alloy33 cladding), ATF-08 (UO2 fuel and Kanthal APMT cladding) and ATF-45 (U3Si5 fuel and FeCrAl Kanthal-AF cladding) were completed. The first two rodlets were sponsored by General Electric, the last was sponsored by LANL. (F. Cappia)

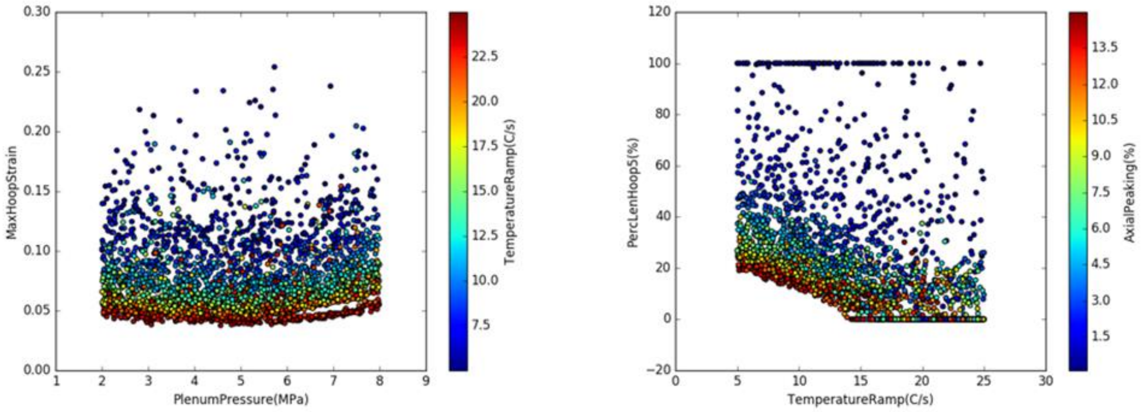
[INL] Vickers microhardness was performed on the cladding of ATF-06 and ATF-08. No hardening of the cladding was measured. (F. Cappia)

1.2.4 LWR Fuel Safety Testing

[INL] Fission gas sample work is continuing. Analysis and sample preparations are being performed for extended PIE on the samples. (L. Emerson)

[INL] Work continues on the hydriding of zirconium tubes. Consistent hydriding is now being achieved. Efforts are underway to increase the consistency of the ppm of hydrides being deposited. This includes a redesign and increase in the use of mechanical components in the system.
(L. Emerson)

[INL] Transient Fuel Performance Modeling – INL, FT-19IN02020403, "Transient fuel performance modeling sensitivity analysis" was completed for Loss of Coolant Accidents (LOCA) for TREAT. Results are shown in Figure 6. (T. Pavey)



Max Hoop Strain (y-axis) vs. Plenum Pressure (x-axis) and Temperature Ramp (Color Scale)

% Length > than 5% Total Hoop Strain (y-axis) vs. Temperature Ramp Rate (x-axis) and Axial Peaking (Color Scale)

Figure 6. Results of transient fuel performance modeling sensitivity analysis completed for LOCA for TREAT.

[INL] Prior to first capsule tests later this year with LVDTs, the Halden LVDT was inserted in the TREAT facility for irradiation effects testing. Multiple fiber optic assemblies were inserted into the TREAT coolant channel to evaluate performance by measuring core temperatures. Results measured from first Gd SPND newly manufactured by a local Idaho small business were comparable with legacy sensors purchased from B&W in 1989. (K. Bowman)

[INL] The MARCH-SERTTA Final Design Review kickoff meeting was held and review activities have begun. This brings independent, third-party review to the design of the project and ensures that the design is adequate for its intended purpose. (D. Dempsey)

[INL] The computed tomography cutting diagram of the SETH-E fueled capsule was completed and is shown in Figure 7. (T. Pavey)

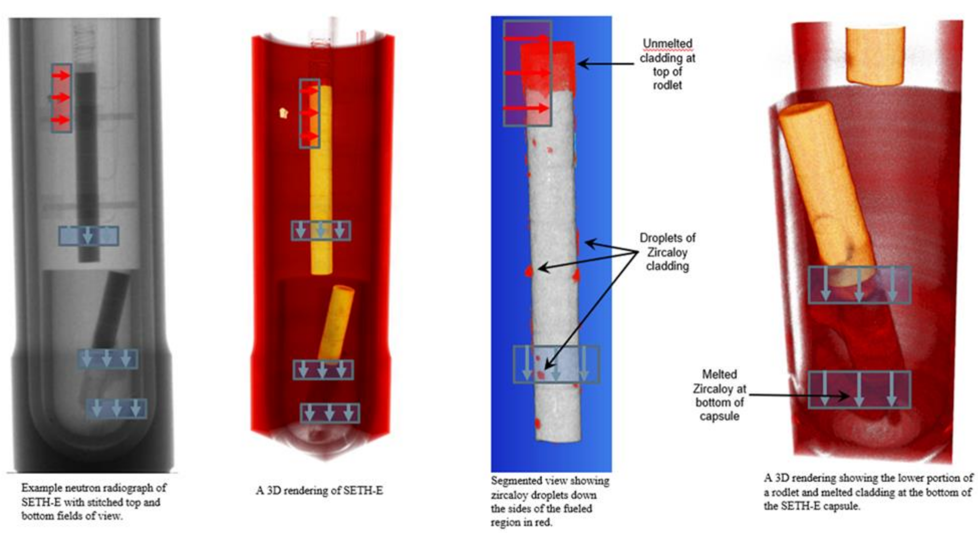


Figure 7. Computed tomography cutting diagram of the SETH-E fuel capsule.

[LANL] The Level 3 Milestone M3FT-19LA020204075, “Enriched UO_2 fuel pellets packaged for shipment to INL,” was completed with the production and characterization of 65 high density UO_2 pellets with geometry, enrichment, and density meeting specifications defined in the fuel specification request letter for TREAT fuel fabrication of undoped, enriched UO_2 fuel pellets. An as-built package detailing processing conditions, geometric dimensions, densities, defects, grain size, O/M, phase purity, isotopics, and impurities for each pellet is being prepared, pending receipt of final analysis of impurities. (J. Dunwoody)

[INL] Assembly and testing of new detector assemblies to be installed next fiscal year continued. (T. Pavey)

[INL] INL personnel visited Orano to discuss needs of C of C for BRR cask. Orano has direction needed to start drafting C of C. (T. Pavey)

[INL] Development of improved modeling and simulation tools continued for use with TREAT experiments. (T. Pavey)

[INL] The Level 2 milestone INL FT-19IN02020401 titled, “Conduct Super-SERTTA Preliminary (60%) Design Review,” was completed. Valuable input and insights were provided during the preliminary design review that will help the project achieve a successful conclusion. The Super SERTTA project is important because, when commissioned, it will be the test vehicle that enables Loss of Coolant Accident (LOCA) testing in TREAT. (D. Dempsey)

1.2.5 LWR Computational Analysis & Fuel Modeling

[BNL] A review of the first results from the uncertainty quantification (UQ) exercise indicated a need to modify the approach to properly initialize the sensitivity cases for the TRACE parametric runs. A new approach to generating the initial states of the sensitivity cases again relies on using the SNAP plug-in for DAKOTA uncertainty analysis. In the new approach, by setting the base model in SNAP (the graphical user interface for building and running TRACE models) to be parametric, DAKOTA first samples the prescribed sensitivity parameters and then sends the values of the variates to SNAP to generate input for the parametric cases. In this setup, each parametric case represents the steady-state input for one of the sensitivity (or sampled) cases. After completing the steady-state run for each sampled case, a TRACE restart run will then conduct the transient calculation and generate the figure-of-merit (FOM) for the UQ analysis. The final step is to pass on the FOM (such as the peak cladding temperature) for DAKOTA to perform the UQ analysis. The complete workflow of this new approach has been exercised and successfully demonstrated. The previously reported uncertainty analysis for the loss-of-offsite-power accident will be redone using this updated approach. (L.-Y. Cheng)

[BNL] Neutronic analyses to support the assessment of the proposed accelerated testing approach for LWR fuels continued. The initial BNL MCNP and Serpent calculations assume a fixed source, essentially on the surface of a bare UO_2 pellet. Both models have been updated based on input from INL to include details of the modeling of the geometry outside the pellet; i.e., the entire irradiation capsule including the fuel pellet as shown in Figure 8. Initial calculations have been performed for full and half-diameter pellets for a linear power of ~320w/cm (roughly twice what is typical of a commercial PWR) and the radial power distributions in ten (10) equal area zones as a function of burnup from Serpent provided to INL for incorporation in BISON fuel performance calculations. (A. Cuadra, M. Todosow)

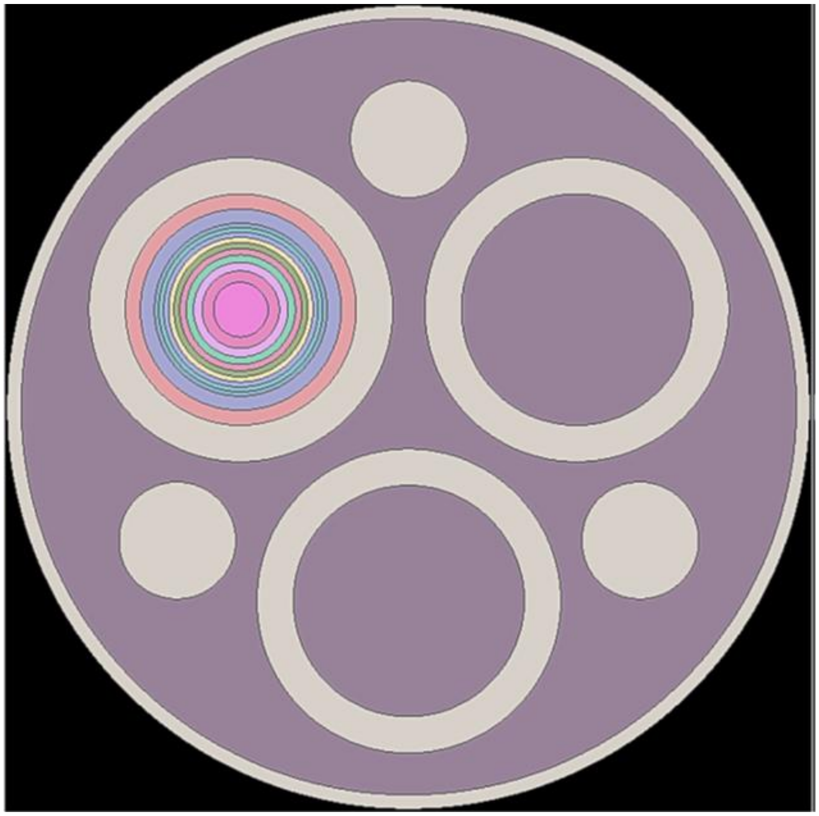


Figure 8. Irradiation capsule Serpent model.

- **[ORNL]** During July, the fuels modeling analysis activities focused on completing Milestone M4FT-19OR020206087, due on August 2. The work focuses on evaluating SiC-SiC cladding performance with U_3Si_2 fuel under normal light water reactor operating conditions. Additionally, analysis of SiC-SiC cladding with UO_2 fuel has been performed for comparison purposes. The analyses were performed using the BISON fuel performance with the incorporation of recently-developed material models. This analysis included assessment of the cladding stress, fuel and cladding temperature, gap closure behavior and fission gas behavior, and incorporates a sensitivity analysis of the impact of design parameters and material properties, about which insufficient knowledge is available.
(B. Wirth)

1.3 Advanced Reactor Fuels

1.3.1 AR Fuels

[INL] Little data exists on the correlation of fuel microstructure and mechanical properties in the U-Zr system. In order to perform some initial measurements, a series of U-Zr alloys from 0-50wt% zirconium have been cast. These samples will undergo hardness testing in the annealed, heat-treated, and as-cast conditions. Follow-on work will include other mechanical properties tests as well. (R. Fielding)

[INL] FY-18 work showed sodium bonding of a metallic fuel with a loosely-wrapped zirconium foil fuel cladding chemical interaction barrier was likely feasible (INL/EXT-18-51600). This was based on ultrasonic inspection of the sodium bond. However, the results of the inspection although promising, were not verified with standards or destructive testing at the time. Recently, several AFC-OA style surrogate rodlets were fabricated and bonded in the same manner as the rodlets used for the FY-18 work. These rodlets were then destructively examined showing that sodium would indeed flow around the foil, creating a thermal bond. (R. Fielding)

[INL] A manuscript has been accepted in *Journal of Nuclear Materials.* The full citation for the article is below:

- Y. Xie, M.T. Benson, L. He, J.A. King, R.D. Mariani, D.J. Murray, "Diffusion behaviors between metallic fuel alloys with Pd addition and Fe," *Journal of Nuclear Materials*, Vol. 525 (2019), pp. 111-124. Online. See https://doi.org/10.1016/j.jnucmat.2019.07.028 (J. Giglio)

[INL] Additional SEM analysis on U50Zr materials was conducted to characterize a subgrain structure that was discovered during work conducted in May. (C. Adkins)

1.3.2 AR Core Materials

[LANL] A manuscript was submitted to JOM titled, "Shear punch testing of neutron irradiated HT-9 and 14YWT." This manuscript investigated the impact of irradiation temperature on a traditional HT-9 compared to an advanced 14YWT alloy. (B. Eftink)

[PNNL] Efforts focused primarily on setting up a contract to have three heats of a 9Cr tempered martensitic steel alloy fabricated. These alloys will explore alternative means to provide irradiation resistance to 9Cr-tempered martensitic steel alloys. The contract is expected to be placed in August, followed by fabrication efforts beginning in September. (M. Toloczko)

[PNNL] Preparation for a lower-dose-rate ion irradiation on HT-9, was completed and specimens were sent to Texas A&M University to be ion irradiated. The irradiation was anticipated to take place in July, but due to their busy accelerator schedule, the irradiation will take place in August. 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] A series of new thermomechanical treatments have been attempted to significantly improve the mechanical properties of HT-9 steels. To investigate the microscopic changes by the treatments, the distribution of local strain (and stress) at the microscopic level was measured for a select of thermomechanical treatments using a SEM-EBSD technique and a digital image correlation (DIC) software. The result shows that large positive and negative strains have developed during processing steps. In Figure 9, large tensile and compressive strains of more than 10% were observed in many locations near relatively larger lath or pocket boundaries. It is also found that the tempering treatment can relax the degree of misorientation among laths and hence the apparent lath (or pocket) size increases with tempering. It is well known that a high residual stress can reduce the fracture resistance of an alloy. Therefore, these stress and strain distributions will be later correlated with the fracture behavior of the newly processed HT-9 steels. (T.S. Byun)

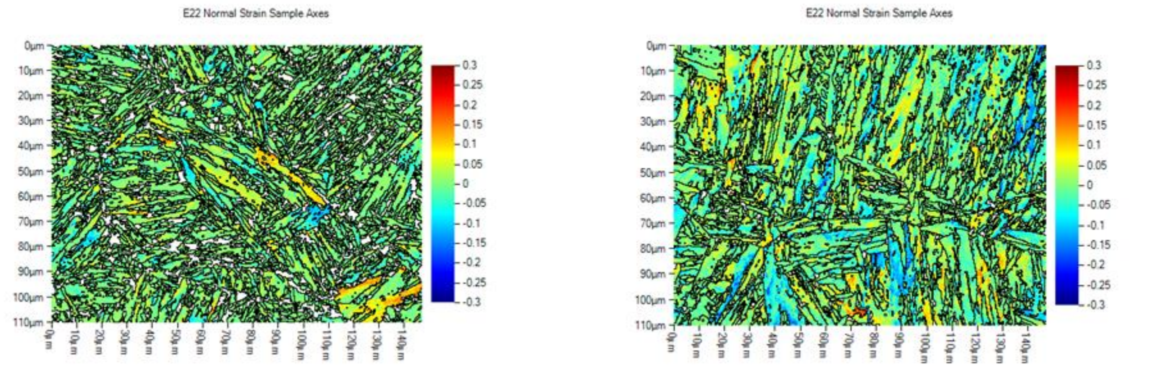


Figure 9. Strain maps in HT-9 steel heat-3 with traditional composition in as-rolled (rapid cooled in air) condition (left) and 600 C tempered condition.

[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 to 36 inches. This will require a longer actuator and longer mandrels and both are currently being procured. After these arrive, they will be installed on the rolling mill so that it is in a pilgering configuration. The pilgering configuration will then be checked out using a stainless steel thick-wall tube. This revised configuration and setup will allow the longer 14YWT tubes to be pilgered next fiscal year. (R. Omberg)

[PNNL] The milestone report, M3FT-19PN020302063 titled, “Characterization of Pilger Processed of 14YWT Tubing,” due on August 15, 2019, is complete and is being processed through Information Release. (R. Omberg)

[ORNL] Three mild steel cans filled with ball-milled powder of the 14YWT heats containing 1%W and Ti additions of 0.2%, 0.3% and 0.4% were degassed. The 14YWT heat containing 0.4%Ti (designated 14YW4T) was extruded through a 2.5 in. x 1.25 in. rectangular-shaped die after heating at 1000ºC. A failure occurred with the extrusion press that prevented the remaining cans of powder to be extruded. The nose and tail of the extruded bar of 14YW4T were cut to reveal the ODS section, which was 9 in. long. The microstructure of 14YW4T will be characterized and will eventually be compared to the two heats containing 0.2%Ti and 0.3%Ti to determine if the Ti level affects the balance of strength, ductility, fracture toughness, and creep properties when compared to past heats of 14YWT that contained 3%W and 0.4%Ti. (D. Hoelzer)

[ORNL] An invited lecture titled, “Materials Challenges for Advanced Reactors Systems,” was given in the Chemistry for Energy and Resources symposium at the International Union of Pure Applied Chemistry (IUPAC) World Chemistry Congress conference in Paris, France on July 5-12, 2019. There were many questions and follow-up discussions regarding this lecture that highlighted the challenges of materials for advanced reactor applications and the advantages that nanostructured ferritic alloys such as 14YWT and OFRAC offer for meeting these challenges as fuel cladding. (D. Hoelzer)

[ORNL] The Level 4 milestone M4FT-19OR020302071 titled, “Report on Use of Machine Learning for Rapid Identification of Defects,” due July 26, 2019, was successfully completed. The related technical report, ORNL/SPR-2019/1200, titled, “Application of Machine Learning Methods for Rapid and Robust Detection of Irradiation-Induced Defects in Nuclear Materials,” summarizes three separate workflows that apply machine learning-based techniques to detect and quantify dislocation loops in electron microscopy images of irradiated FeCrAl alloys. The report provides the current progression by the research team, including techniques for both static images and dynamic videos and compares the results to human-based hand-counting techniques. In all cases, the machine-learning approaches replicate the data produced using hand counting, but eliminate researcher-to-researcher bias and significantly reduce the analysis time. This work is being pioneered by Prof. Dane Morgan at the University of Wisconsin and shows how existing datasets produced within the program can be leveraged for new and interesting research topics and collaboration. (M. Shen, G. Li, W. Li, D. Wu, H. Adusumilli, J. Greaves, W. Hao, N. Krakauer, L. Kurdy, Y. Liu, J. Perez, V. Sreenivasan, B. Sanchez, O. Torres, K. Field, D. Morgan)

1.3.3 AR Irradiation Testing & PIE Techniques

[INL] The Advanced Test Reactor (ATR) 166A irradiations cycle has begun. 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 the 168B cycle. AFC-4D capsules will reside in canal storage post-168A until approximately start of CY-21, and then be shipped to PIE. (C. Murdock)

[INL] The AFC-FAST experiment group is in its final design phase with mechanical design now complete and thermal analysis and fabrication development activities making progress. The fabrication of actual capsule components has started. 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] 02 Analytical chemistry for burnup on X521-G594 (U-Pu-Zr-Ga) and X430-T653 (U-20Pu-10Zr) continued. Nondestructive examinations on three legacy EBR-II fuel pins (X486-J555: U-10Zr. X496-CL39, X496-CL47: U-10Zr, long-life experiment) continued. (L. Capriotti)

[INL] The status report for the AR Hot Cell Furnace (Level 3 milestone) was completed and submitted ahead of schedule. The assembled fixture was sent to the instrument lab for operational testing. (M. Cole)

[ANL] A journal article titled, “Fuel Performance Evaluation of Annular Metallic Fuels for an Advanced Fast Reactor Concept,” by Y. Miao, et al., was published in *Nuclear Engineering and Design*, 352 (2019). In this paper, the fuel performance of annular metallic fuel with HT9 cladding in a novel advanced fast reactor design optimized for high-burnup (peak burnup of 26.8%) performance was evaluated using the BISON code. 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 for both upper and lower plenum configurations. It is evident 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 fission gas plenum configuration effectively lowers the gas pressure inside the rod and reduces the creep damage accumulation in the HT9 cladding. (T. Kim)

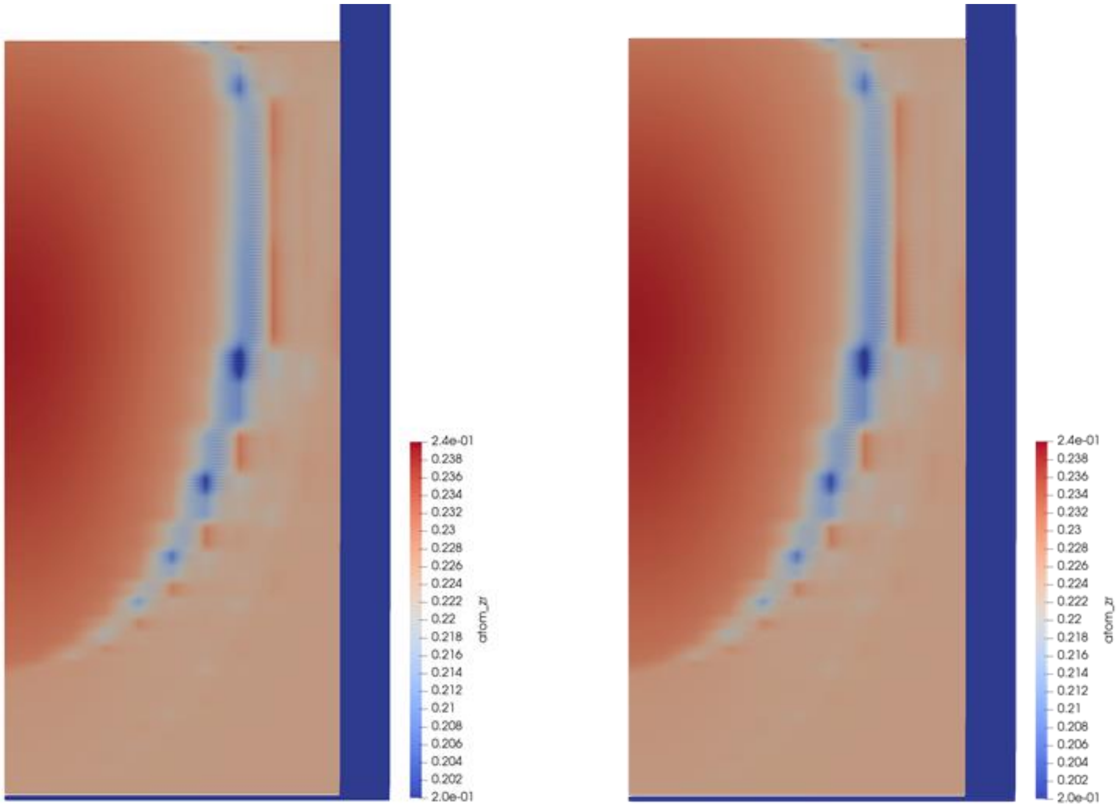
1.3.4 AR Fuel Safety Testing

[INL] The Level 3 milestone for issuing an F&OR for a heat sink module utilizing the MARCH system was accomplished ahead of schedule. Work has continued on the design of the THOR module. (L. Emerson)

[INL] INL personnel traveled to ORNL to see their transient furnace to support early design considerations for the metal fuel furnace. Conference abstracts were submitted highlighting our transient testing plans and PIE efforts on legacy materials for the metal fuel safety work. (T. Pavey)

[INL] The benchmark for EBR-II OPT-1 ternary pin clad in HT9 was completed. Results are shown in Figure 10. (T. Pavey)

- No tuning of BISON input parameters
- 24-hour preconditioning allowed a Zr redistribution profile to develop
- Zr profile unaffected by ~5 minute transient.



Pre-transient At transient peak

Figure 10. EBR-II OPE-1 ternary pin clad in HT9 benchmark.

1.4 Capability Development

1.4.1 CX Fuels

[INL] The sensors in the LFA were changed out. Technicians are continuing to work out the vibrational "noise" associated with the TCM. Representatives from Netzsch were at INL the week of July 29 to troubleshoot equipment. (S. Martinson)

[INL] Testing of source lasers continued. The Cobalt laser was coupled into a fiber to improve the beam quality, but the power output was substantially reduced. We are now testing a fiber-coupled laser from another project. (D. Hurley)

1.4.2 TREAT Testing Infrastructure

[INL] The Level 3 milestone titled, "Complete F&OR for I-Position loop design," was completed ahead of schedule. (T. Johnson)

[INL] HFEF Upgrades to Support MARCH-SERTTA F&OR" document is in eCR review. Commenced drafting "HFEF Upgrades to Support Refabrication of Irradiated Fuels F&OR."

[INL] The Level 3 milestone titled, “Experiment handling capabilities to assemble and disassemble the MARCH-SERTTA are established,” was completed ahead of schedule. (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] All experiments for M2FT-19IN030102012, “Evaluate the aqueous phase radiation chemistry and radioprotective mechanisms of aqueous miscible ligand derivatives to aid the future design of radioprotective extractants,” have been completed. Analysis and draft manuscript preparation are underway. This research focuses on evaluating the radiation robustness of a series of aqueous miscible CMPO analogues (phosphonic acids) to further our understanding of activated radioprotection in a medium in which fundamental radiation chemistry is well established. (G. Horne)

[INL] A manuscript titled, “Effect of Chemical Environment on the Radiation Chemistry of N,N-di-(2-ethylhexyl)butyramide (DEHBA) and Plutonium Retention,” was submitted to Dalton Transactions (latest impact factor: 4.099) in collaboration with the French Alternative Energies, and Atomic Energy Commission (France), and California State University Long Beach. This research investigates the radiation robustness of the monoamide ligand N,N-di-(2-ethylhexyl)butyramide (DEHBA) and its two major degradation products, bis-(2-ethylhexyl)amine (b2EHA) and N-(2-ethylhexyl)butyramide, (MEHBA), as a function of absorbed dose and chemical environment (single phase in n-dodecane, and biphasic in contact with 0.1 or 3.0 M nitric acid). Irradiated solutions were then evaluated by a series of distribution ratio experiments, using tracer uranium and plutonium solutions, to determine the effect of ligand degradation on envisioned process performance. (G. Horne)

[INL] A manuscript titled, “31P NMR Study of the Activated Radioprotection Mechanism of Octylphenyl-N,N-diisobutylcarbamoylmethyl Phosphine Oxide (CMPO) and Analogues,” was published in *Dalton Transactions* (latest impact factor: 4.099), in collaboration with Western Michigan University, Valparaiso University, Brookhaven National Laboratory, and California State University Long Beach. The presented work, a combination of experiment and calculation, investigates the activated radioprotection mechanism of Octylphenyl-N,N-diisobutylcarbamoylmethyl Phosphine Oxide (CMPO) and its analogues, dioctylphenylphospine oxide (DOPPO) and trioctylphosphine oxide (TOPO), as a function of absorbed dose and chemical environment (single phase in n-dodecane, and biphasic in contact with 0.1 or 3.0 M nitric acid). The citation is: Horne, G. P.; Kiddle, J. J.; Zarzana, C. A.; Rae, C.; Peller, J. R.; Cook, A. R.; Mezyk, S. P.; Mincher, B. J. 31P NMR Study of the Activated Radioprotection Mechanism of Octylphenyl-N,N-diisobutylcarbamoylmethyl Phosphine Oxide (CMPO) and Analogues. Dalton Transactions, 2019, 48, 11547–11555. (G. Horne)

[ONRL] A summer student has been hosted at ORNL to perform theoretical calculations of Am/Eu selectivity for a new aminopolycarboxylate ligand that has been synthesized at ORNL and is being tested now at INL. A variety of different DFT flavors and several post-Hartree-Fock methods including RI-MP2, DLPNO-CCSD(T), CASSCF(6,7), and CASSCF-VEVPT2+SO using ECP and all-electron calculations have been tested to infer which effects play a major role in enhancing selectivity for 5f versus 4f trivalent metal ions. We find that increasing the size of the basis set, employing MP2 versus DFT calculations, and incorporating spin-orbit effects all lead to the increase in the Am/Eu selectivity. These calculations will be extended for the other three ligands with experimentally-measured Am/Eu selectivities to determine which method is capable to correctly predict the trend in selectivity and the absolute values. (S. Jansone-Popova)

[ORNL] A new batch of octapa ligand (8.6 grams) was synthesized and sent to collaborators at INL for further testing, along with 2.2 grams of (4aR,8aR)-1,4-bis(2-ethylhexyl)octahydroquinoxaline-2,3-dione, a preorganized bidentate ligand. This new preorganized ligand will be tested as a sole extractant of lanthanides – possibly replacing a mixture of neutral and acidic extractants used to achieve efficient actinide/lanthanide separation. (S. Jansone-Popova)

[ORNL] A manuscript titled, “Selectivity and Speciation of Trivalent Americium and Rare Earth Extraction with Bis-Lactam-1,10-Phenanthroline Ligand in a Hydrocarbon Solvent System,” has been resubmitted to the Royal Society of Chemistry publisher. (S. Jansone-Popova)

2.2 Waste Form Development and Performance

2.2.1 Electrochemical Waste Forms

[ANL] The responses in initial tests highlighting the intrinsic dissolution resistance of iron phosphate waste forms made with dehalogenated Echem waste salt indicated materials can be made that are more durable than optimized glass-bonded sodalite waste form and as durable as borosilicate waste glasses. However, the results of tests being conducted to assess the long-term durabilities of two materials that represent a range of iron phosphate waste form compositions indicate the dissolution rate does not decrease with reaction time. Figure 11a and Figure 11b each show initial results of modified ASTM C1285 (PCT) tests conducted in DIW at 90 °C with crushed specimens of DPF5 280 and DPF5 336. Tests with DPF5-280 are being conducted at glass surface area-to-solution volume (S/V) ratios of about 500 m^{-1} (filled symbols) and 1500 m^{-1} (open symbols) and tests with DPF5-336 are being conducted at 500 m^{-1}. The linear increases seen in all tests indicate dissolution is not being attenuated by either decreasing solution affinity or surface layer formation effects. The difference in S/V ratio only has a minor effect on dissolution of DPF5 280, which is essentially an alkali iron phosphate glass, and both tests indicate preferential release of Li and Na. The results of the test with DPF5 336, which is mostly crystalline, suggest all of the Na and Cs is being released from the glass phase, whereas much of the Li and P is being retained in more durable $LiFePO_4$ crystalline phases. The initial results of modified C1220 tests being conducted with each material also indicate constant releases. Tests are continuing to determine if the dissolution rates slow eventually and the reacted solids will be examined after the tests are terminated. (W. Ebert)

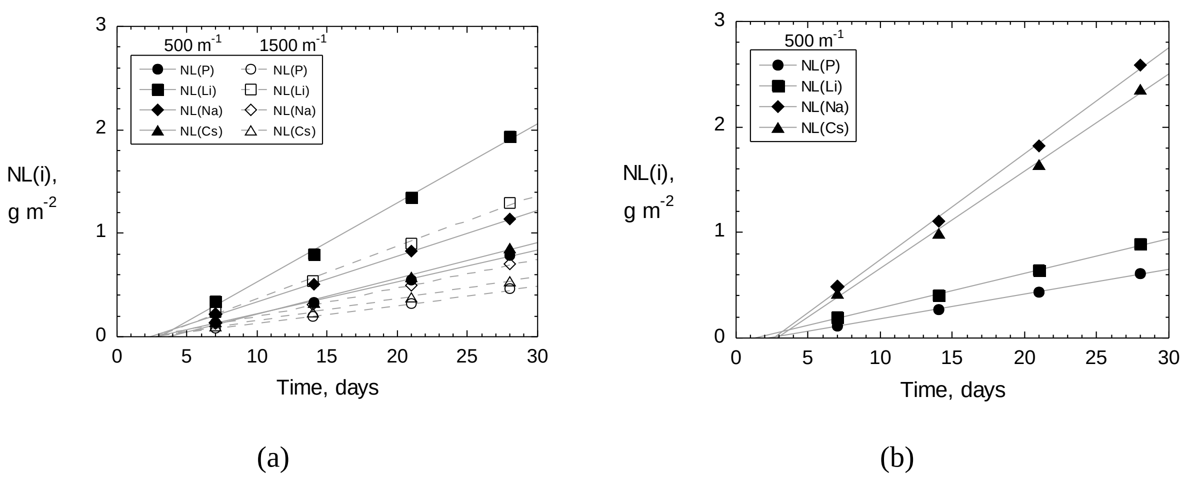


Figure 11. Results of modified PCT conducted with (a) DPF5 280 and (b) DPF5 336 iron phosphate waste form materials.

2.2.2 Glass Ceramics Waste Forms

[ANL] Long-term modified ASTM C1285 (PCT) tests are in progress to assess the effects of the solution composition on the on-set of Stage 3 and the Stage 3 dissolution rate. Figure 12 shows the initial results of tests with six glasses at 90 °C. The compositions and test results for the Batch and Blend glasses are very similar. Stage 3 behavior occurred early in tests at high pH, but the Stage 3 rates are similar at both pH values. Stage 3 also occurred early in the test with HM glass at the highest imposed pH and in all three tests with EA glass. Note that high pH values were imposed when the tests were initiated, but the pH is allowed to drift during the tests. Also, the specific areas of the crushed glass used in the modified PCTs are both about 0.03 $m^2 g^{-1}$, so NL(B) will be about 33 g m^{-2} when all the glass has dissolved. Samples collected through 122 days are being analyzed. (W. Ebert)

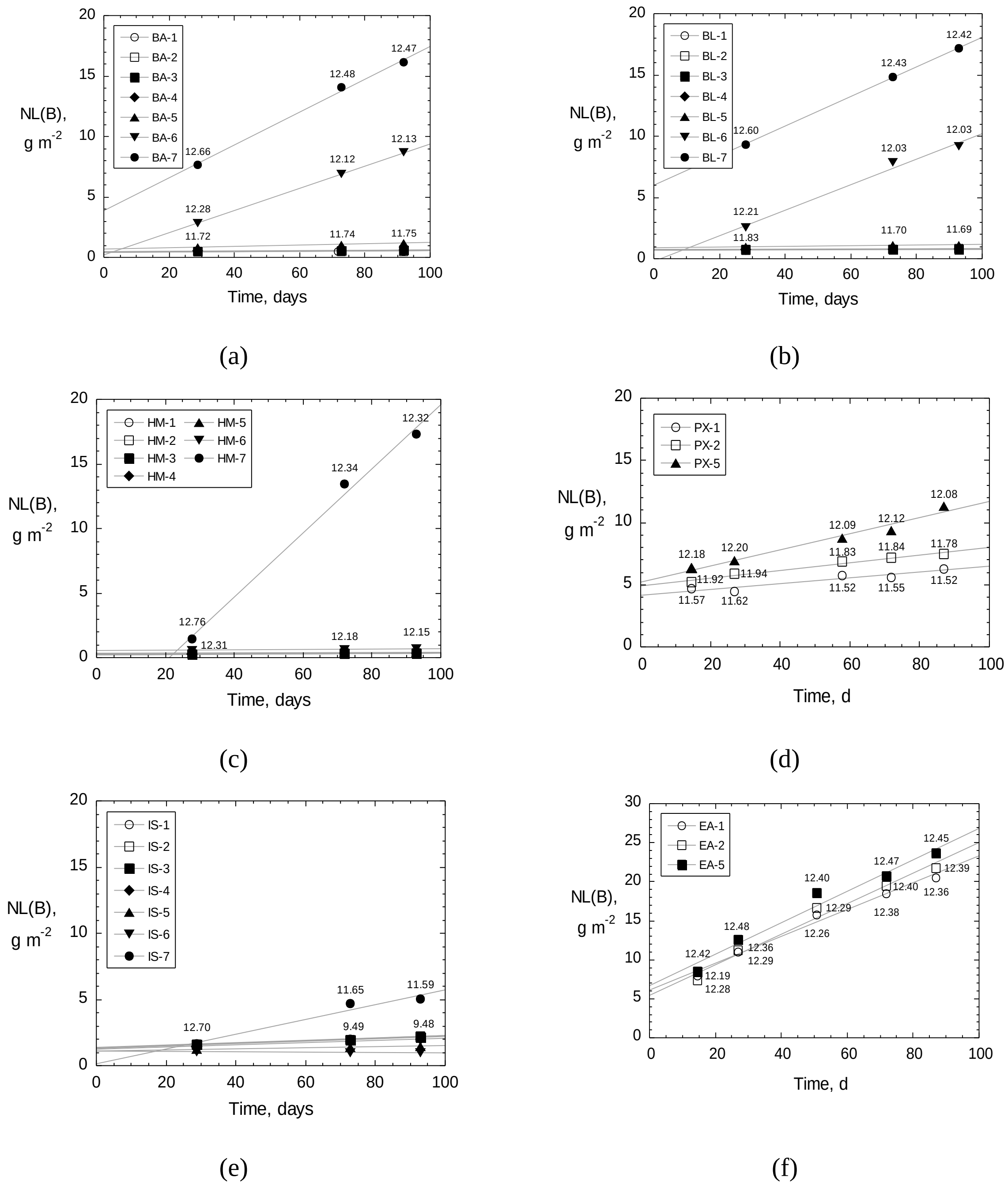


Figure 12. Initial results of modified PCTs with (a) Batch, (b) Blend, (c) HM, (d) Purex, (e) ISG, and (f) EA glass conducted at various imposed pH. Numbers show pH(RT) values measured for each sampling.

[PNNL] Through the Murdock Charitable Trust, a grant program dedicated to enabling research opportunities for high school science teachers, we have welcomed Hermiston, Oregon, chemistry teacher Anna Reuter to help us build and perform experiments using an in situ microscale Raman spectrometer. By using the unique system, Ms. Reuter will be able to see differences between the bulk fluid and the fluids in confined spaces. Variations in the Raman frequency shift measured at selected points will be related to changes in the local concentration and electrochemical activities of species involved in corrosion reactions occurring at the substrate as a function of immersion time and conditions. The studies will investigate wide varieties of constricted spaces that result from corrosion processes. This will include contact between different material types in corrosion feedback conditions. (J. Ryan)

2.2.3 Iodine Waste Forms

[ANL] Tests with HIPed mordenite materials made by ORNL remain in progress. (W. Ebert)

2.3 Domestic Electrochemical Processing

[ANL] Operation of the engineering-scale cell continues to be optimized for kilogram-scale demonstrations of U/TRU co-deposition operations scheduled to be performed in FY-20. Larger anode basket assemblies and newly-designed crucibles to collect the approximately 1-kg U/TRU product are being fabricated. Analyses of deposition products are planned for August. (W. Ebert)

[ANL] Electrochemical corrosion tests were conducted with Zircaloy-2 in molten LiCl-1% Li_2O salt to characterize the corrosion behavior of Zircaloy and redox behavior of Li_2O. Tests indicate the dissolution and formation rates of ZrO_2 layers and deposition of Li metal at various operating potentials pertinent to UO_2 oxide reduction. (W. Ebert)

2.4 Sigma Team for Off-Gas

[INL] A long-term deep-bed adsorption test that was started in April 2019 continued through July. 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 over 1,900 hours. Periodic gas sampling has confirmed 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, 3, and 4. By month end, the methyl iodide concentration at the outlet of Bed 1 has exceeded 90% of the inlet methyl iodide concentration.

Methyl iodide has been detected at the outlet of Bed 4 (with a cumulative bed depth of 4.9 in.) during July, but the methyl iodide concentrations in the Bed 4 outlet gas was still low at around 0.1 ppmv. No breakthrough of methyl iodide from Bed 5 has yet been detected.

The most recent set of sorbent sample analyses indicates that the sorbent is approaching 100% saturation based on the chemisorption equation Ag + I = AgI. For this reason, this test is near completion and will end in August 2019. (N Soelberg)

[ORNL] The Level 2 Milestone report titled, "Design and test an off-gas capture system for advanced tritium pretreatment," has undergone technical review and editing and is expected to be issued on schedule (August 2, 2019). This report now includes the analytical results that were pending at the time the draft report was issued. In addition to the conclusions presented last month primarily on the tritium capture and recovery, the following conclusions related to the iodine recovery can be drawn from the analytical results received in July:

- Full recovery can be achieved for both sorbates when no sorbent is in place, indicating no accumulation within the test system, and implying no hold-up within the system.
- Analysis of the AgA iodine sorbent beds from the integrated tritium and iodine tests indicate quantitative iodine recovery can be achieved (within anticipated experimental errors). Thus, this system may provide a means for the quantification of the iodine released by the ATPT process within the experimental uncertainties. This would support 0.33 to 1.00 kg demonstrations of the ATPT process with actual used nuclear fuel.
- Iodine penetrated further into AgZ than into AgA when operated in gas recirculation mode.
- No visible corrosion was observed in the test system. (R. Jubin)

[ORNL] The designed test matrix for aerogel was continued. The reference capacity of AgAerogel for CH_3I was 250 mg I/g AgZ (the balance of the feed stream was dry air). A test exposing a thin bed of AgAerogel to 50 ppm CH_3I and 1% NO (balance dry air) at 165°C was performed. The loading curve is shown in Figure 13, along with the reference run. The capacity of AgAerogel for CH_3I in the presence of 1% NO was 100 mg I/g AgZ. These iodine loadings will be verified by neutron activation analysis. A second test was conducted that exposed AgAerogel to a gas stream containing 1% NO_2 (balance dry air). During testing, the weight was observed to continually decrease. Upon examination of the sorbent, it appeared that the sorbent was disintegrating and flowing out of the sample holder with the gas stream. Some powder deposits were observed outside the sample holder. (B. Jubin)

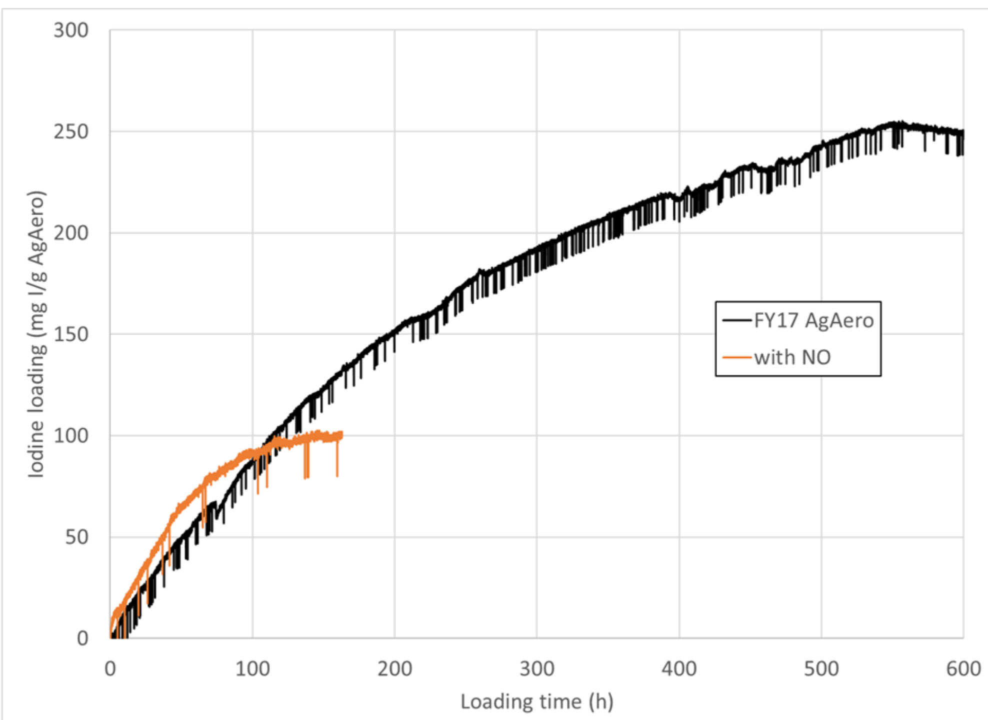


Figure 13. Comparison of CH_3I adsorption on AgAerogel with and without 1% NO in the inlet stream.

[ORNL] Results of a supporting milestone for the task, "Conduct additional tests and provide technical review support for reengineered Silver Functionalized Aerogel," were transmitted to PNNL. PNNL has indicated that they are not requesting further tests at this time. ORNL will continue to support with review of the associated PNNL Level 3 milestone as needed. (R. Jubin)

[PNNL] The Level 4 milestone M4FT-19PN030107038 titled, "Scale up and ship mechanically robust room and low temperature adsorbent for testing at INL," was completed. Around 50 grams of newly-engineered form of room and low-temperature MOFs were shipped. (P. Thallapally)

2.5 Flowsheet Demonstrations

[ORNL] The draft report on the purification of the recycled Zr has been completed and submitted for ORNL review and is awaiting final management approval and classification review. This report is in support of the associated milestone M3FT-19OR030206015. It is expected that this report will be released in early August. (R. Jubin)

[ORNL] Bill DelCul and Bob Jubin participated in a one-day review of the Hybrid Zircex Technology Development efforts that was held in Salt Lake City on July 25. The objective of the meeting was to identify the technical gaps that need to be filled to finish design and fabrication of a Hybrid-ZIRCEX process that will incorporate ZIRCEX, solvent extraction, vitrification, and solidification/conversion. (R. Jubin)

[ORNL] A series of comparative parametric chlorination studies have been initiated in collaboration with INL using HCl/N_2 on aluminum coupons using a fluidized bed reactor process to optimize the processing conditions. (R. Jubin)

[ANL] Zero-point testing was completed where the maximal heavy-phase throughput was measured for a variety of 2-cm rotor designs and fabrication techniques. Initial zero-point testing was conducted using deionized water, followed by tests with dodecane. The maximum heavy-phase flow rate was determined to be significantly lower for dodecane when compared with water, which suggests that surface tension plays a role in determining optimal weir geometry. Hold-up testing is also ongoing and expected to be completed this month. The volume and O/A ratios of the liquids contained within the mixing and separating zones of a 2-cm contactor stage are being measured for various rotor designs for different feed flow rates and O/A ratios. The priority at this point is to collect as much data as possible for various permutations (rotor fabrication technique, O/A ratio, throughput flow rate, rotor opening diameter, etc.) to better observe trends that can be used to improve the design process. Once hold-up testing is completed, the data will be compared with the existing ROTOR code in order to determine what improvements can be made. Experimental work will also continue to better predict the transient behavior, average residence time, and stage efficiency of the contactors. (P. Candido)

[ANL] A Jupyter notebook was created using Python code to quantitatively compare AMUSE Excel results with AMUSE Fortran results. The user specifies the .xls report file (Excel) and the .xlm report file (Fortran), and then graphs can be generated for components in the flowsheets generated with both codes. The user can specify D values, aqueous or organic concentrations, for comparison. Using this aid, we can more quantitatively evaluate small differences between the Excel and Fortran AMUSE simulations. (P. Candido)

[PNNL] A recommended protocol for uranium conversion to oxide during the upcoming lab-scale (1.5 kg) HALEU demonstration was provided to personnel at Idaho National Laboratory in fulfillment of milestone M3FT-19PN030206039 titled, "Complete initial U conversion protocol." The recommended method involves precipitating the uranium from the uranyl nitrate solution by addition of 30% H_2O_2 at 55 °C, digestion of the resulting $UO_4{\cdot}4H_2O$ at 55 °C for 2 h, then allowing the mixture to cool and the solid to settle. The $UO_4{\cdot}4H_2O$ is collected by filtration, then it is calcined in a muffle furnace to yield either UO_3 or U_3O_8, depending on the calcining temperature. (J. Vienna)

[INL] The Hybrid ZIRCEX Demonstration started fabrication of a uranium polishing demonstration at Central Facilities, as shown in Figure 14. The demonstration has two purposes: (1) inform future design for the Hybrid ZIRCEX engineering scale demonstration and (2) provide small, research-scale UO_2 HALEU specimens that meet the feedstock specifications for advanced reactor developers. (M. Patterson)

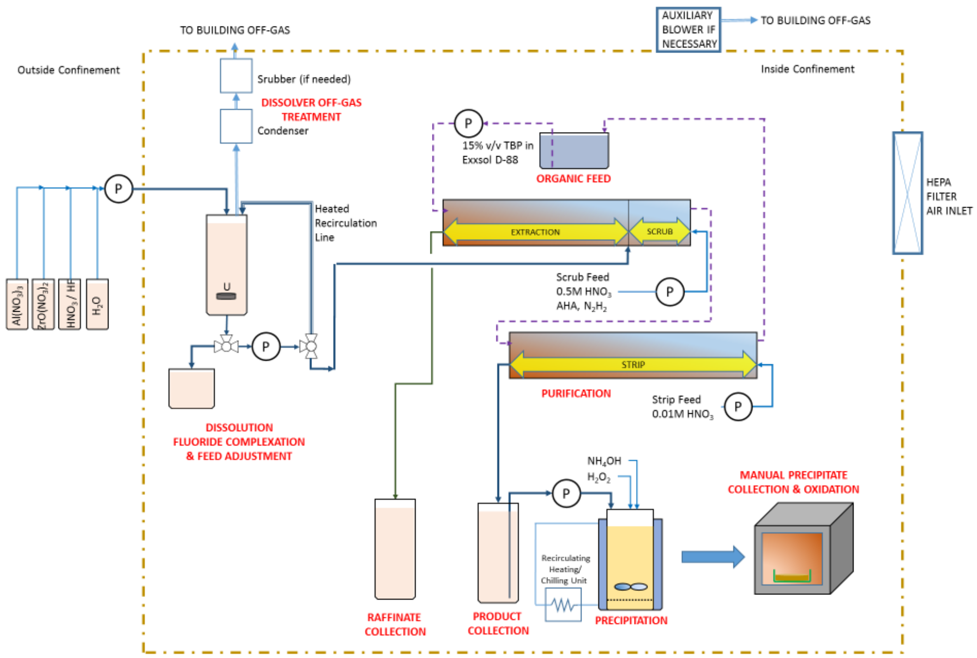


Figure 14. Uranium polishing demonstration flowsheet.

[INL] More than 20 engineering studies were completed and submitted to the Demonstration management team. These studies provide important inputs into the Functional and Operational Requirements (due in September) that will be the basis for Conceptual Design of the Hybrid ZIRCEX Demonstration. The topics and performing organization for each of the studies is shown in Table 1. (M. Patterson)

Table 1. Topics and performing organization for each of the engineering studies.

Engineering evaluations - complete by end of FY2019

	Process Flow Diagram	Hydro-chlorinator Heating & Cooling	Product Spec	Analytics Service & Rqmts	Time & Motion	NEPA Strategy	Criticality Eval	Off-gas Study	Vessel Heating & Cooling	Materials	Utility Sizing
BEA			√			√					√
AECOM	√				√			√	√	√	
MPR		√	√	√			√				

	Permitting	HLW Storage & Waste Disposition	Cask / Fuel Receipt	Product Packaging	Shielding	Building Code	Physical Protection	Support Services	Siting Alternatives	Site Investigation	Functional & Operational Rqmts
BEA	√	√	√			√	√	√	√	√	√
MPR					√						
AECOM				√							

[INL] Experts from across the DOE complex, design engineers from MPR and AECOM, and BEA personnel reviewed technical uncertainties for the Hybrid ZIRCEX Demonstration. A workshop in Salt Lake City on July 25, 2019, identified technical gaps to be addressed in progressively larger-scale demonstrations, culminating at engineering scale in the Hybrid ZIRCEX Demonstration. The gaps were combined with those previously known to form the basis for a Technology Roadmap, and are summarized in the matrix shown in Table 2. (M. Patterson)

Table 2. Technology uncertainties matrix

Technology Uncertainties	MRPP	Gram-scale U polishing	Kg-scale U separations	U conversion	Vitrification	Pilot-scale Back-end Demo	Hybrid ZIRCEX
Decladding	√						√
Cladding capture	√						√
Pneumatic transfer	√						√
U capture	√	√	√				√
Bed material life	√						√
Heating / Cooling needs	√	√	√	√	√	√	√
Off-gas management	√	√	√		√	√	√
Dissolution needs		√	√			√	√
Seps efficiency, impurities		√	√			√	√
Volumes and rates	√	√	√	√	√	√	√
Confirming enrichment management				√		√	√
Feedstock types (oxides, metal)				√		√	√
Wasteform					√	√	√
Logistics	√	√	√	√	√	√	√

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

3. MPACT CAMPAIGN

3.1 Advanced Fuel Cycle Scoping

3.1.1 Advanced Process Modeling and Simulation

[PNNL] Finalized the five samples for LANL. These samples include, two dissolved high burn-up spent nuclear fuel samples from Three Mile Island and Quad Cities-2 (ATM-109), a recently fissioned sample of HEU (Z10924), a sample of tank waste (241-AP-107), and a smear of a cut fuel pellet from the sister rods. Once these samples are ready to be received by LANL, they will be shipped for assay using the microcalorimeter. Initial mass spectroscopy measurements of the ATM-109 fuel indicates there is nearly 100 ug of uranium per milliliter.

3.1.2 MSR Safeguards

[ORNL] Developed a technical note on the dose assessment calculations. Working on a technical note on the technical safeguards questions to provide necessary input to complete the parametric study.

3.1.3 MSR Safeguards – Modeling

[SNL] Continuing to support the MSR safeguards and interfacing with ORNL. The MSR safeguards model is being refined for work for next year.

3.1.4 Advanced Fuel Cycle Scoping Review Panel

[ANL] Reviewed the MPACT Advanced Fuel Cycle Panel scoping report and began updating sections on electrochemical processing, CoDcon and Zircex.

3.2 Safeguards and Security by Design – Echem

3.2.1 Microfluidic Sampler

[ANL] Experimental activities focused on the assembly and fit testing of the custom two-chamber oven and molten salt sampling loop components. Design efforts were initiated for the vessel sampling conduit that will replace the test loop's lower reservoir in the deployable system. Began developing plan for processing of remaining UREX+ demo samples for shipment to LANL for testing of microcalorimeter gamma detectors. The samples will be recovered, dried, and packaged into sealed vessels for shipment.

3.2.2 Actinide Sensor

[INL] Activities include fabricating U-membrane tubes that are free of cracks, U-sensor testing, and sensor characterization. Successfully fabricated several crack-free U-membranes for sensor testing. Identified that too-low-temperatures for ion exchange of Na-beta" alumina tube in UCl3 may lead to cracking of the beta" alumina tubes.

3.2.3 Bubbler for Measuring Density and Depth of Molten Salt

[INL] Laboratory instrumentation (pressure transducers) were calibrated in preparation for molten salt experiments. Drawings were submitted to the fabrication shop to make a fixture to secure bubbler tubes during the molten salt tests. This fixture allows for the insertion of cartridge heaters to test the Marangoni effect as a clogging mechanism. The triple bubbler installed in HFEF was cleaned using the water circulator that was recently developed. The "clean" bubbler has yet to be hooked up to validate the cleaning process.

3.2.4 ER Voltammetry

[ANL] Fabrication of the voltammetry sensor components for installation into the INL IRT electrorefiner is nearing completion. Final assembly will be completed in the coming days. Experimental operations in ANL's electrorefiner are continuing in order to prepare for the transition to Idaho.

3.2.5 OR Voltammetry

[INL] Clean Ir, SS, and Mo materials in LiCl salt were tested as working electrodes using Ir and Ni metals as reference electrodes. In all cases, the counter was SS. All materials were stable and did not show signs of degradation. Incremental amounts of Li2O were added during CV tests. Ideal operational procedures were identified for Ir as a working electrode. During the systematic CV tests, a strong feature was observed on the cathodic CV scans that is present on SS, Ir, and Mo at ~-0.4 - ~-0.6 V, indicating some species in the LiCl-Li2O salt. Analysis is being performed to understand the strong feature.

3.3 Modeling Advanced Integration and Milestone 2020

3.3.1 Modeling and Simulation for Analysis of Safeguards Performance

[SNL] The model update is complete and new data sets were generated for LANL.

3.3.2 Advanced Integration (Models)

[SNL] The models are being prepared for runs for next fiscal year.

3.4 Exploratory Research/Field Tests

3.4.1 Microcalorimetry

[LANL] Expecting to receive samples from PNNL and ANL in August for the user assessment. PNNL has finished preparing and packaging five samples from two different irradiated fuel materials and waste from the Hanford process. ANL is now packaging a set of 23 samples from throughout the UREX+3a process. INL has said that pyroprocessing samples may be able to ship from HFEF to LANL in September. Katrina Koehler presented recent results at the 18th International Workshop on Low Temperature Detectors in Milan, Italy. Her presentation on automated microcalorimeter data processing software was very well received and won an award for "best poster." Mark Croce traveled to the IAEA laboratories in Seibersdorf, Austria, to discuss microcalorimeter capabilities. This was a very productive visit that identified two primary topics of interest for IAEA safeguards: decay energy spectroscopy for plutonium and uranium isotopic analysis in small samples, and x-ray spectroscopy for U/Pu elemental analysis. A set of 12 decay energy spectroscopy samples from seven different materials was prepared and will be shipped to LANL in August. Mark Croce presented results from the field test instrument SOFIA at the Institute for Nuclear Materials Management annual meeting in Palm Desert, California. Feedback on the presentation noted the rapid pace of microcalorimeter technology development and opportunities for on-site measurements.

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] Attended the FY-20 Planning Package Meeting of the Nuclear Fuel Cycle and Supply Chain Office held at DOE HQ, July 30-31, 2019, and presented the work scope and budget splits by labs. The campaign activities for FY-20 have been restructured into three areas: Campaign Management and Integration, Nuclear Energy System Performance (NESP), and Economic and Market Analysis for Nuclear Energy Systems.

4.2 Equilibrium System Performance (Esp)

4.2.1 Performance of Fuel Cycle Systems

[ANL] Collected information on the melt-refining technology and the MOSART reactor concept. The melt-refining technology was developed to implement an economic continuous recycling of used nuclear fuels in fast reactors. The overall fuel cycle using the melt-refining process has been demonstrated in the EBR-II and Fuel Cycle Facility. The MOSART (Molten Salt Actinide Recycler and Transmuter) is a 1000 MWe Russian molten-salt reactor concept for TRU incineration. Burner and breeder concepts have been designed based on the FLiBe/TRUF3 salt and FLibe/(ThF4,TRUF3) salt, respectively.

4.2.2 Economic Analysis Capabilities and Assessments

[ANL] Draft input was developed and provided to the OECD/NEA Expert Group on Uranium Mining Economic Development (UMED). This included two documents: one on the business and capacity development that will result from the economic input of a uranium mine, and the second was on the socio-economic impact of uranium mining in Wyoming.

[ANL, BNL, INL, LLNL] A conference call with the campaign management was held on July 17, 2019. The status and updates of the public versus private report were discussed during the call and the report is on pace for the first complete draft to be provided for review by August 16, accommodating the feedback provided during the conference call. Completed the draft section on the Superconducting Super Collider (SSC) and revised the Advanced Photon Source (APS) section. INL provided the summary results of the literature review and BNL completed a revised section on the National Synchrotron Light Source II. Work has begun on the lessons learned section. A VTR case study is being investigated to see if it needs to be included in the report.

[INL] To support the study on private versus public management of nuclear facilities, a draft of the literature review was submitted to task team members for review. This draft included a list of factors found in the literature to be factors contributing the project outcomes (cost, schedule, quality). Moreover, a review of other components of the study was completed, where these components were drafted by team members at other locations.

[PNNL] Contribute to Beyond LCOE modeling effort on U.S. electric power sector.

[BNL] Provided additional information on the NSLS-II construction lessons-learned to ANL for inclusion in "Report on Drivers of Cost Differential for Public versus Private Nuclear Facilities."

4.2.3 Daily Market Studies of Advanced Nuclear Energy Systems

[ANL] Developed methods for modeling energy storage in the market analysis using the EDGAR code. The implementation of the developed methods into the EDGAR code will continue in the coming month.

[ANL, BNL] Updated MARKAL results, which will be utilized to revise the energy market analysis performed in the previous analysis, and presented at GLOBAL and coming ANS meeting.

[BNL] Provided MARKAL analyses to ANL for inclusion in their studies to assess the competitiveness of advanced and current nuclear technologies and the various benefits they bring in different U.S. electricity grid market scenarios.

4.2.4 Enhancements to the Cost Basis Report (CBR) Tool

[ANL] Drafts for new modules were completed, which include.

- Module D1-6A: Contact-Handled Metallic or Metal Alloy Uranium Fuel Fabrication provides cost estimates for the fabrication of blankets, LEU (high assay LEU), and HEU metallic fuels. The costs have significant uncertainties, but the mean values are estimated at $437/kg for blankets, $633/kg for HALEU, and $1,300/kg for HEU fuels.
- Module D1-6B: Contact-Handled U/Pu Metallic Alloy Fuel Fabrication provides cost estimates for the fabrication of driver fuels form LWR derived Pu and from the Pu derived from recycle of that used SFR fuel. There are significant uncertainties in these costs, but the means are $1,623/kg and $2,073/kg, respectively. This indicates a significant cost increase for the first recycle of the SFR used fuel.

4.2.5 Analysis of NES to Augment Information in Fuel Cycle Catalog

[INL] Assessing information describing how bringing high-assay low enriched uranium (HALEU) into the fuel market impacts on the current fuel-cycle infrastructures. Also, a set of calculation problems were created, which could address issues related to core design, fuel storage/transportation, and economic impacts when utilizing the HALEU fuel for the current existing LWRs.

4.2.6 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.

4.2.7 Campaign Special Sessions at International Topical Conference

[ANL] Developed potential topics that could be discussed for the GLBOAL 2019 panel session, Sustainable Strategies for Nuclear Energy Systems under Future Energy Market Environments.

4.2.8 Quick Turn-Around Studies

[**ANL, BNL, INL, LLNL, ORNL**] In order to support a 90-day study involving DOE-NE, developed a white paper on the front-end fuel cycle needs for deployment of advanced reactor concepts relative to the existing commercial technologies. The paper discusses the needs of fuels derived from natural uranium only and excludes fuels with thorium and recycled fuel materials. In the paper, the fuel types of associated advanced reactor concepts being developed in the U.S. and Canada are summarized, and the technical challenges, investment needs, and RD&D needs are discussed.

[**LLNL**] Participated in a quick turn-around effort led by campaign management at ANL to prepare a white paper requested by DOE-NE regarding "front end fuel cycle needs for deployment of advanced reactor concepts in the U.S. relative to the existing commercial technologies available."

4.3 Development, Deployment and Implementation Issues (DDII)

4.3.1 Transition Analysis Studies

[ORNL] A draft of the M3 report "Application of Cyclus to a Transition Scenario" has been completed and comments incorporated. A draft has been sent to campaign management for comment.

[ORNL] The two conference papers submitted to ANS Winter Meeting, "MSR uncertainty analysis for fuel cycle assessments" and "Implementation of a MOX Neural Network for Fuel Cycle Modeling" have been accepted to presentation.

[ANL] The upgraded version of DYMOND on the AnyLogic® platform (DYMOND6) was used to successfully complete the first unit test of the international FIT Benchmark activity, which is part of the work scope for ANL's M3 deliverable on Transition Analysis. The fuel loading model (based on a direct burnup solution) in DYMOND6 was used to calculate the required Pu content for MOX-PWR fuel for several thousand Pu isotopic vectors. The trends were similar to those of other codes and confirmed that DYMOND6 does have the particular functionality that accounts for the reactivity impact of different Pu isotopes.

[ANL] Using DYMOND6, the OECD-NEA international benchmark results for an example transition scenario were updated to include the impact of Pu isotopes, decay, first core loads, and other modeling capabilities that were not available in the previous version of DYMOND5. The preliminary results are consistent with those from other international participants.

[ANL] DYMOND6 was coupled to Dakota as a first test of the feasibility of using DYMOND6 and its new database format with another tool that enables sensitivity analysis, uncertainty quantification, and optimization. The feasibility is being tested by conducting a sensitivity analysis of spent fuel cooling time on various transition metrics for the OECD benchmark transition scenario. Success of this exercise may lead to coupling DYMOND6 with other tools such as RAVEN or the NEAMS Workbench.

[INL] Working to complete workscope for the August Transition Analysis milestone report. This includes an analysis of Partial Transition Scenarios and documentation of NEA benchmark test case results and improvements to the VISION fuel cycle simulation.

4.3.2 Regional and Global Impacts

[PNNL] Completed milestone deliverable on Regional and Global Nuclear Analyses. The report titled, "Load Leveling Through Battery Electric Vehicles and Implications for Electric Power Generation," by S. Kim, was delivered to NTD on schedule.

[BNL] Provided input to PNNL on "Assessing Long-term Benefits of Nuclear Energy Economic, Energy, Environmental and Social Aspects" for inclusion as an Appendix in their deliverable report

4.3.3 Adaptation of OR-SAGE for NES Analysis

[ORNL] Work has continued on the development and evolution of the GIS mapping assessment work. The data processing for siting the fuel cycle facilities is ~90% complete and a review of the results is underway. The logistics framework for the fuel transportation optimization is 70% completed. The ORACLE server is set up and we started working on the data geoserver framework for the tool. Initial tool set-up should be completed by end of August, and from which a report will be produced. In addition, and by way of a demonstration, SMR siting datasheets (assessments) were completed for 27 U.S. fuel cycle facilities and four DOE national laboratory sites. The results were integrated from the generated visual datasheets into a draft report and provided a summary of the siting issues for each location. The results will be included in the final report by way of examples.

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

5. JOINT FUEL CYCLE STUDY ACTIVITIES

A joint ERWG/SSWG joint Expert's Meeting was held the week of 19 August at INL. The condition of received irradiated fuel and processing test plans with irradiated LWR fuel were reviewed

A third 4 kg-scale test with DUO2 was completed in the oxide reduction system to optimize 4kg-scale operation parameters for LWR fuel

4 irradiated LWR fuel elements were declad in preparation for irradiated LWR processing tests.

Thermal cycling and melt-interaction studies were completed on advanced ceramic crucibles with positive results.

Two manuscripts evaluating advanced aluminosilicate aerogels and xerogels for fission product capture in process offgasses were completed and are in the review process.

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 completed 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, to be included with the award checks.

University Research Alliance prepared 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 prepared the 2019 Innovations Awards announcement for the nucleartechinnovations.org website.

University Research Alliance assisted First Place winners in submitting summaries for the Innovations Awards special session at the ANS Winter Meeting in November. All of the summaries were submitted by the ANS extended deadline of July 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.