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NUCLEAR TECHNOLOGY RESEARCH AND DEVELOPMENT TECHNICAL MONTHLY FEBRUARY FY18

ADVANCED FUELS CAMPAIGN

ADVANCED LWR FUELS

LWR Fuels

- **[LANL]** Energy-resolved neutron imaging data on transmutation fuels (Figure 1A) containing Am and Np were reanalyzed. The analysis using the SAMMY code was focused on retrieving absolute densities for five isotopes, 238U, 239Pu, 240Pu, 241Am and 237Np. The bulk composition described by partial densities of the main isotopes 237Np, 239Pu, 240Pu, and 242Am, resultant from the initial analysis agreed to better than 0.1 g/cc with the partial densities determined by mass spectrometry, except for 238U, which was overestimated by the initial approach. It was found that due to only a single resonance of 238U present in the fitted energy range of 1eV to 9eV (Figure 1B), the refined areal densities for 238U were statistically insignificant, resulting in large errors. Consequently, the fitted energy range was extended to 24eV to include a second 238U resonance (Figure 1C, D), which stabilized the 238U areal densities, providing excellent agreement for all five isotopes. (A. Losko and S.Vogel)

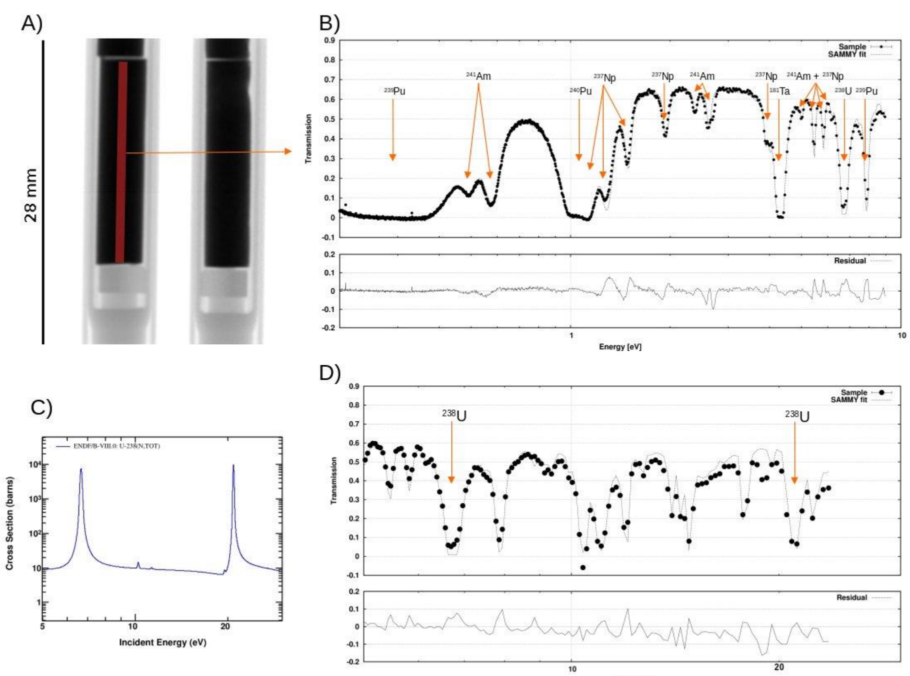


Figure 1. A) Radiograph using 0.2eV neutrons of two transmutation fuel slugs. B): Initial fit from 1-9 eV of transmutation fuel containing Am and Np. C): ^{238}U cross section extracted from ENDF database. D) Extended fit to 24eV for improved ^{238}U areal densities.

- **[LANL]** Assessment of the thermal diffusivity of UB_2 and UB_4 pellets that were sintered to high densities (>90% TD) via SPS in RPI (June 2016) is continued. The thermal diffusivity of these samples was previously measured up to 1000°C and this measurement was extended to 1500˚C for the UB_2 pellets (Figure 2). The results indicate that the thermal diffusivity of UB_2 increases past 1000˚C. This behavior has been also predicted via a first principles study of the thermal properties of UB_2 [E. Jossou, et al., *J. Nucl. Mater.* (2017)]. Further thermal diffusivity measurements on the UB_2 and UB_4 samples are ongoing and, in particular, at the high temperatures relevant to accident tolerance. (E. Kardoulaki and U. C. Nunez)

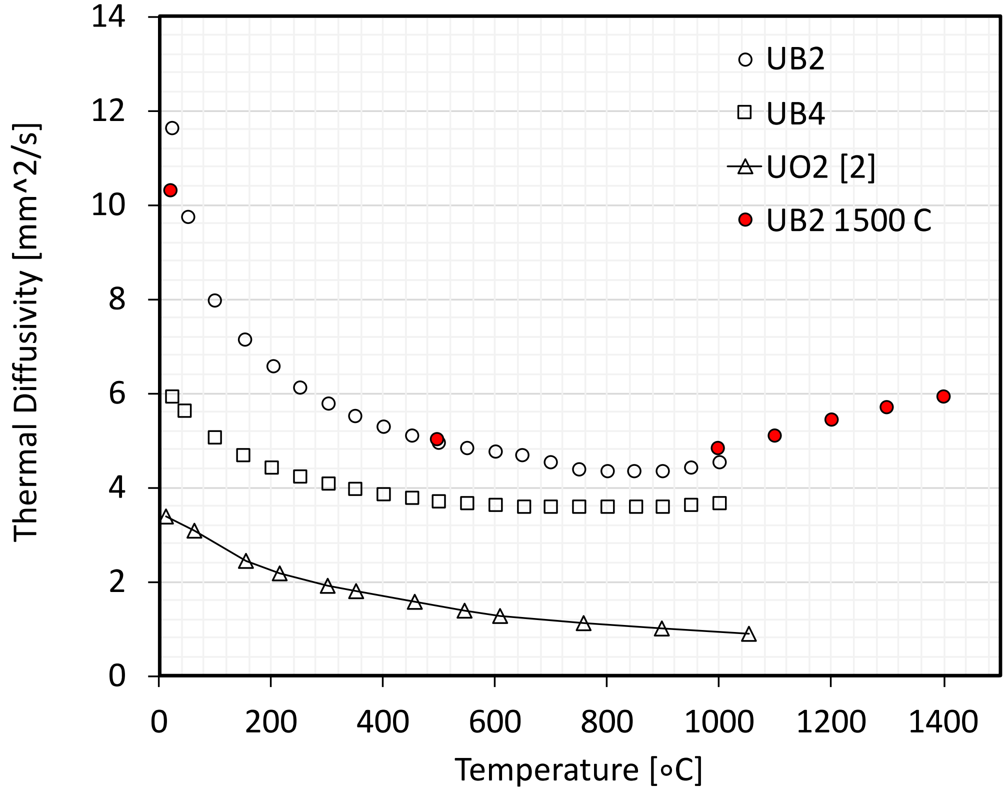


Figure 2. Thermal diffusivity as a function of temperature up to 1500°C for UB_2 (circles) and 1000˚C for UB_4 (squares) samples along with reference thermal diffusivity data on UO_2 [J. Fink, J. Nucl. Mater. (2000)]. (triangles).

LWR Core Materials

- **[ORNL]** The Level 3 milestone (M3NT-18OR020202071) titled, "Summary report on characterization of HT-9 produced using powder-based additive manufacturing," due February 22, 2018 was completed. A technical report, ORNL/SPR-2018/780, titled, "Preliminary characterization and mechanical performance of additively manufactured HT9," provides the preliminary analysis on feasibility of using laser blown powder additive manufacturing to fabricate HT9. Following fabrication, two post processing heat treatment cycles were employed to study the influence of post processing on mechanical strength and microstructure. The AM fabricated HT9 in the as processed and post processed conditions shows significant improvement of strengths and ductility compared to those of the wrought materials. We would like to highlight that this is the first time this has been demonstrated and indicated feasibility of AM techniques for advanced reactor materials development. (N. Sridharan and K.G. Field)

- **[LANL]** Initial TEM has been performed for C26M FeCrAl aged in air for extended time periods at temperatures from 300-600ºC. This study was conceived as a high oxygen bounding condition to assess the thickness of oxide that may be formed in pile on the inner cladding surface. Similar work performed previously centered on a commercial alloy, Kanthal APMT, showed a strong dependence of oxidation temperature on the rate of oxide coarsening and degree of crystallinity. Exposure of C26M to the same conditions has so far been found to yield a thinner oxide layer. As an example, aging of APMT at 600ºC for 100 hours yielded an oxide layer approximately 35 nm thick; C26M was found to grow an oxide of only 24 nm during the same test. Neither of these oxide thicknesses would be expected to significantly affect tritium migration. Ongoing examination will provide data for time intervals of up to 2000 hours and provide conclusions regarding the concern presented by tritium mobility in uncoated/untreated C262M (N. Li). (A. Nelson)
- **[ORNL]** A manuscript summarizing recrystallization texture formation in FeCrAl alloys with Mo and Nb additions has been prepared to be submitted to a scientific journal. Characterization and evaluation of recrystallization texture developments in two representative wrought ATF-FeCrAl alloys (Fe-13Cr-6Al-2Mo and Fe-13Cr-6Al-1Nb, weight percent) during rolling-and-annealing processes were summarized, depicting the simulated microstructure evolution during the thin-wall FeCrAl tube fabrication. The internal review process at ORNL is being initiated. (Z. Sun, Y. Yamamoto)
- **[LANL]** Deuterium leak standards were sent to Vacuum Technology, Inc. for refill and recertification. The leaks were installed in the system and will be evacuated for a few days. Measurements of permeation through candidate FeCrAl alloys will continue. (S. Maloy)

LWR Irradiation Testing & PIE Techniques

- **[INL]** Cycle analysis, experiment reconfiguration, and experiment insertion into the ATR for cycle 162B-1 were completed in time to support an early ATR cycle startup date (12 days early). Additionally, shipment analysis has begun which should support an on time shipment of irradiated capsules from ATR to HFEF for PIE. (D. Dempsey)
- **[INL]** The ATF-2 (fuel test) final design review was completed and comments are being incorporated in design documents. Fabrication of experiment components is in progress. (G. Hoggard)
- **[INL]** Optical microscopy was completed on the U3Si2 – Zirlo ATF-1 samples. An example of the mid-plane longitudinal mount from ATF-1W R4 is shown in Figure 3 below. (J. Harp)

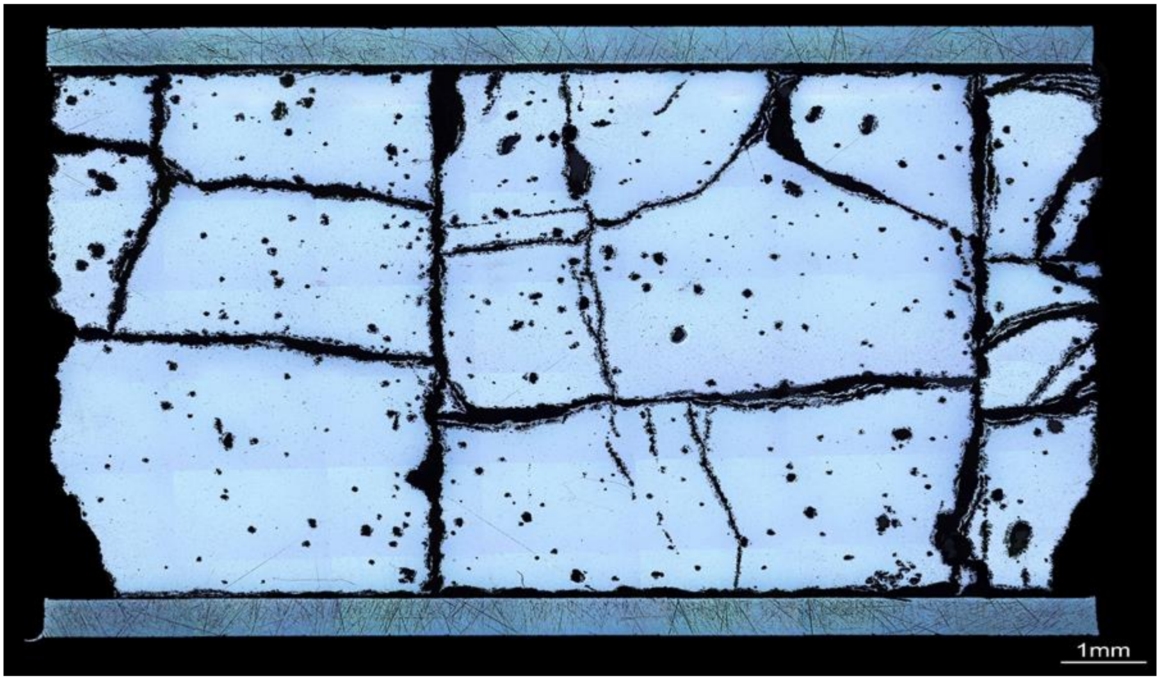


Figure 3. Example of the mid-plane longitudinal mount from ATF-1W R4.

- **[INL]** Microhardness testing was completed on the U_3Si_2 – Zirlo ATF-1 samples. The Vickers Hardness was observed to be slightly higher after irradiation than the as fabricated material (Figure 4). (J. Harp)

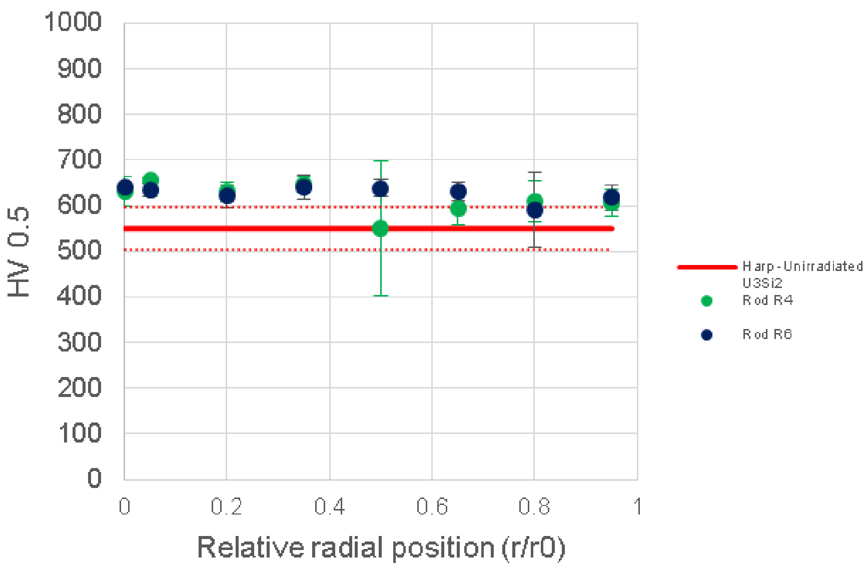


Figure 4. Vickers hardness before and after irradiation.

- **[INL]** The current status of ATF-PIE was presented at the EPRI/INL/DOE joint workshop on ATF in Fort Worth. (J. Harp)

LWR Fuel Safety Testing

- **[INL]** Fabrication drawings are complete and have been sent to the fabrication shop planning group for planning and scheduling. One bid for the secondary can fabrication has been received. As of February 25th, we are still awaiting a bid from the other fabricators. (D. Dempsey)
- **[INL]** Neutronic and thermal ECARs are ready for technical check. Everything is on track for an April final design review. (D. Dempsey)
- **[INL]** Transient prescription predictive analysis continues to make good progress. MCNP/SERPENT predictions have progressed to the point where MAMMOTH work can begin. (D. Dempsey)
- **[INL]** The MPFD and TC amplifiers were tested during a transient at TREAT on February 14 using the DAS system. The TC amplifiers performed well during the test and didn't appear to be affected by the transient. The MPFD electronics also didn't appear to be affected by the transient. (J. Schulthess)
- **[INL]** The electrical drawings for the DAS system have been completed by the drafter and have been reviewed. Corrections to the drawings are nearing completion. Assembly of the DAS instrumentation cabinet will begin as soon as the drawings are finalized. (J. Schulthess)
- **[INL]** Minor modifications were made to the endcaps for the LBW process in order to allow for insertion into the laser welding system at TTAF. Threads were added to the endcap and a shank was fabricated in order to give the weld setup adequate standoff distance from the rotating chuck so the lasing head can be positioned correctly. (J. Schulthess)
- **[INL]** Installation of a secondary inert gas purge line was initiated on the TTAF laser welder system to provide adequate cover gas to the root area of the weld, i.e. provide cover gas inside the tube weldment. Complete cover gas, both to the top of the endcap and to the inside of the tube, is imperative for titanium welding and the use of the TTAF laser welder has been on hold until the full purge system was installed. This work is ongoing and should be completed by the beginning of March. NOTE: the purge gas install has been in the works for several months and was not a modification made/paid for by this project. (J. Schulthess)

LWR Computational Analysis & Fuel Modeling

- **[INL]** An initial model of the coated ATF cladding was developed. Current activities are underway including:
  - Identification of coatings used by ATF
  - Development of calculation matrix of prototypic coatings and thicknesses
  - Evaluation of impact of coating on cladding creep-down, fuel temperature and FGR
  - Evaluation of coating integrity during reactor operation, shutdowns, and restarts
  - Evaluation of coating integrity during cladding ballooning (P. Medvedev)

Industry FOA

- **[INL]** Installation of the sintering furnace was completed. Assembly, shipping, and installation of the tri-arc furnace was completed. The High Density Fuels Glovebox/Sintering Furnace Acceptance Test Plan was issued. Installation of the hot zone and lift assist for the sintering furnace was completed. (P. Wells)
- **[ORNL]** In order to provide relevant data for accident models, steam oxidation testing is being conducted on the new 2nd generation FeCrAl tubing, C26M, the same cladding inserted into Plant

Hatch in 2018. A series of seven LOCA burst tests was conducted on two batches of C26M. The second batch of C26M tubes with optimal processing showed higher rupture temperatures. (B. Pint)

ADVANCED REACTOR FUELS

AR Fuels

- **[INL]** During characterization of the co-extruded Zr/U-Zr alloys reported in January, both alloys showed a zirconium concentration gradient from the Zr can toward the center. Whether this gradient existed in the original billet or not was not known at the time. During the month of February archival pieces removed from the front of the billets during the machining process were microstructurally characterized. The samples were mounted and polished using standard metallographic processes and examined using energy dispersive x-ray spectroscopy (EDS). Figure 5 below shows an x-ray map of the U-10Zr billet taken near the edge of the billet. EDS analysis showed zirconium content on the outside of the billet being slightly higher than the center portions of the billets. However, this gradient was significantly smaller than the gradient seen in the extruded product. Based on these results, it is likely that the zirconium gradient seen in the extruded product may have been due to the extrusion process not the initial billet. Work has also progressed toward fabrication of several U-10Zr and U-6Zr billets in preparation for additional extrusion work. These billets will be used to reproduce previous studies to show repeatability, can be used for further billet characterization, and to further optimize the extrusion process. (R. Fielding)

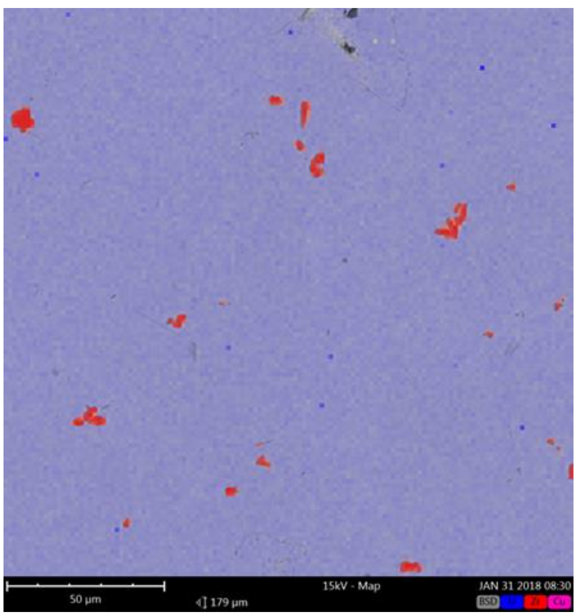
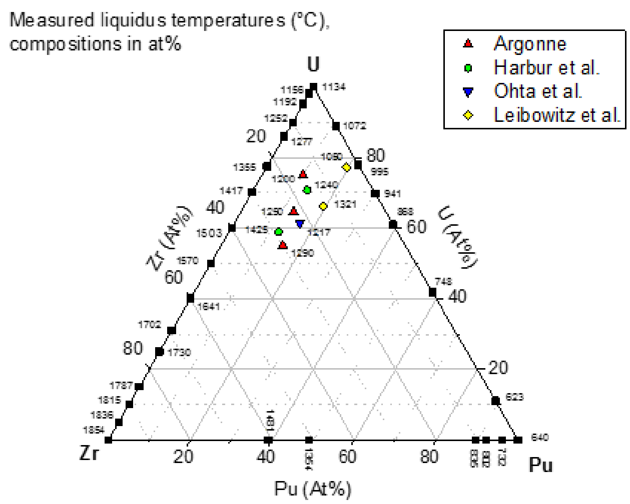
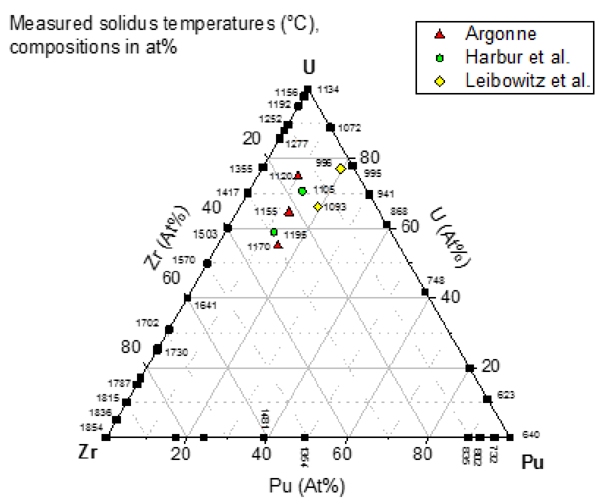


Figure 5. U-10Zr billet edge x-ray map. Notice no definite zirconium gradient.

- **[INL]** Novel fuel form work included an initial attempt to produce a quartz mold to cast fuel with three separate grooves along the length. The fabrication attempt was done by inserting a graphite core into a quartz tube then applying a rough vacuum and heat to collapse the quartz onto the graphite. However, once the quartz was hot enough to soften and collapse, the quartz was very heavily oxidized. It is assumed that this was due to only a rough vacuum being applied. A second attempt is ongoing in which the graphite core was sealed around a graphite mandrel under a hard vacuum. The sealed quartz will be heated in a furnace to collapse the quartz onto the graphite core. If successful, after heating the quartz will be cut and the graphite removed. Several 10 mm U-10Zr slugs were also cast to begin forging experiments using a hot uniaxial press installed in a glovebox. If successful this work may be able to produce annular ternary fuel through a forging process. (R. Fielding)

- **[INL]** One new feature of the 2018 update will be incorporation of triangular plots generated with Origin software. These plots will make it easy to visually compare and understand data from complex alloys in ways that are impossible with two-dimensional plots. Figure 6 below shows the experimental measurements of the liquids and solidus of ternary U-Pu-Zr alloys. Data from U-Pu, Pu-Zr, and U-Zr binary systems is included to aid in interpretation. All of the data from ternary alloys is from compositions with relatively high proportions of U, which were selected because of their perceived importance for developing nuclear fuels. **All of these figures should be considered preliminary.** (C. Papesch)





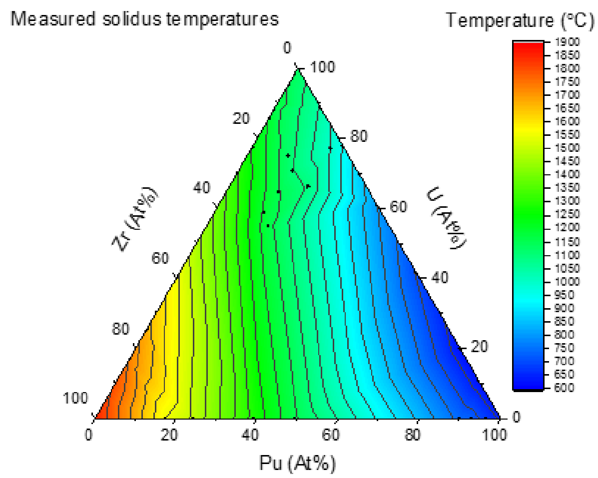


Figure 6. Data for U-PU-Zr. Data for U-0Pu-Zr alloys is from measurements reported by Argonne National Laboratory (Report ANL-7155, Kelman t al. 1965, Kittel et al. 1971) and Leibowitz et al. 1988, Los Alamos National Laboratory (Harbur et al. 1970), MT+ETAPHIX programme (Ohta et al. 2011), U-Zre data is from measurements reported by Balakrishnan et al. (2016), Pu-Zr data is from measurements reported by Y. Okamoto et al. (1999), and U-Pu data is from the U-0PU phase diagram of H. Okamoto (1996). Small black symbols in the contour plot correspond to data values in the figure at left.

- **[INL]** Two metallic fuel additives, tin and palladium, are being investigated for their effectiveness to control FCCI. Scanning electron microscopy (SEM) analysis of the annealed samples of U-20Pu-10Zr-3.86Pd and U-20Pu-10Zr-3.86Pd-4.3Ln (Ln=53Nd-25Ce-16Pr-6La) was completed. Analysis of the data is underway. The samples have been transferred to IMCL to have lamella cut on the FIB, followed by transmission electron microscopy (TEM) analysis. This work is a direct follow-on to the previous as-cast characterization of these alloys. (C. Papesch)
- **[INL]** The following manuscript was submitted in February describing the as-cast SEM and TEM characterization: M. T. Benson, L. He, J. A. King, Robert D. Mariani, A. Winston, J. Madden, "Microstructural characterization of as-cast U-20Pu-10Zr-3.86Pd and U-20Pu-10Zr-3.86Pd-4.3Ln," *J. Nuc. Mater,* submitted.
- **[INL]** The following journal article, also investigating Pd as a fuel additive, was accepted for publication in February: M. T. Benson, L. He, J. A. King, R. D. Mariani, "Microstructural characterization of annealed U-12Zr-4Pd and U-12Zr-4Pd-5Ln: Investigating Pd as a metallic fuel additive", *J. Nucl. Mater*, 2018, *502*, 106-112. (C. Papesch)
- **[INL]** During the investigations with Sn as a fuel additive, a possible ternary phase was observed in the characterization of U-10Zr-4.3Sn-4.7Ln, as well as U-10Zr-2Sn-4Ln. SEM analysis of as-cast 11Zr-37Sn-52Ln was completed. The analysis of the data is underway. The sample has been annealed, and is ready for further SEM analysis. TEM and X-ray diffraction (XRD) is also planned on the annealed sample. (C. Papesch)
- **[INL]** In PIE results (U-10Zr with HT-9 cladding) and in out-of-pile diffusion couples between U-10Zr with a Fe-based cladding (either Fe or HT-9), three possible ternary phases have been observed, χ, λ, and ε phases. These phases have only been proposed based on SEM analysis, and have not been fully characterized. The fabrication and as-cast SEM characterization of these phases was completed, and the samples were annealed. The annealed samples are ready for further SEM characterization. TEM and XRD are planned on the annealed samples. (C. Papesch)

- **[INL]** Arc melting of NpO2 under safe gas appears to have successfully reduced it to neptunium metal. (L. Squires)

AR Core Materials

- **[PNNL]** Preparation for investigations of the tensile properties and microstructure of the three newly fabricated 9Cr ferritic-martensitic steels began. The first batch of tensile specimens were machined, but found to be out of dimensional specification, so another set will made. TEM foil preparation is underway with one foil already prepared for each alloy. The TEM exams will take place in March. (M. Toloczko)
- **[PNNL]** Further work was performed on completion of a manuscript describing a new method for identifying clusters in atom probe datasets. This paper will be submitted for review in *Ultramicroscopy* in March. (M. Toloczko)
- **[LANL]** High temperature hydrostatic extrusion was performed on two 14YWT tubes at CWRU by Dr. J.J. Lewandowski at 815C. Extrusion was successful and tubes are being etched from the cladding material. (S. Maloy)
- **[ORNL]** The NSUF Rapid Turnaround Experiment (RTE) proposal (18-1130) titled, "Post-irradiation analysis at the nanoscale of 14YWT after high dose (16.6 dpa) neutron irradiation at 386C and 412C," led by M.A. Auger, Oxford University, UK and D.T. Hoelzer (ORNL) was accepted for funding. The PIE research will use instruments located in the Low Activation Materials Development and Analysis Laboratory (LAMDA) at ORNL for preparation of specimens from TEM disks that were neutron irradiated at BOR-60 at ~386ºC and 412ºC to a dose of ~16.6 dpa. The specimens prepared by lift-out/FIB will be analyzed by TEM at LAMDA and by APT at Oxford University via separate funding not associated with the RTE. The anticipated results will advance the current understanding of neutron irradiation effects on the microstructural stability of 14YWT that will benefit the development of advanced fuel cladding in fast reactors. (D. Hoelzer)
- **[ORNL]** Data was collected using atom probe tomography (APT) of the MA957 sample previously creep tested for ~61,000 h at ~825ºC and 70 MP using the Cameca LEAP 5000 XR at the Max-Planck Institut Für Eisenforschung (MPIE). Several specimens were analyzed, and the results showed that the average radius of the nanoclusters was ~1.6 +/-0.6 nm with a number density near 1 x 1024/m3. These results show that the Y-Ti-O enriched nanoclusters present in MA957 experienced no coarsening during the ~61 kh creep test, which is a very remarkable result demonstrating the long-term stability of the nanoclusters at high temperatures. A manuscript titled, "High-Temperature Creep of MA957: Part I - Microstructural Observations," that covers these results is under internal review and will be submitted for publication in the near future. (D. Hoelzer, C. Massey)
- **[PNNL]** As part of the program to fabricate tubing from difficult-to-fabricate materials, the PNNL rolling mill is being modified so that it can perform pilgering of tubes. This will establish a unique research and development capability within the DOE complex. The design of the rollers needed to perform pilgering is nearing completion and the precise radii on the grooves in the rollers is being confirmed. A Solid Works drawing of the rollers is being used to develop a drawing which can be sent electronically to a machine tool file. This machine tool file can then be sent to Precision Products, Inc. which can then machine directly from this file. Although it was originally thought that the machining could be performed in the PNNL machine shops, the machining is sufficiently complicated and requires such precision, that it has been found that it will be necessary to send this work out to the Lab. (R. Omberg)
- **[PNNL]** The report for the PNNL milestone report due 31 March 2018 is nearing the final stages. The report will focus on and report on the modifications to the rolling mill as needed to develop a

pilger mill. The milestone is: M3NT-18PN020302052 'Modify rolling mill and perform initial pilgering operations to develop process parameters." (R. Omberg)

- **[ORNL]** Dual-ion irradiated T91 was procured from University of Michigan to serve as a surrogate material for characterization testing prior to further execution of testing on ACO3 HT9 duct material. (K. Field)
- **[PNNL]** Changes in distribution of chemical elements in thermomechanical processing (TMP) were investigated using a scanning transmission electron microscope (STEM). STEM-EDS analysis was completed for the original and N-doped HT-9 steels in as-quenched and fully tempered conditions (Figure 7). Little boundary segregation of alloy elements is observed in the as-quenched steels consisting of martensite or ferrite laths while carbide particles with enriched or depleted elements are clearly observed in the fully tempered steels. Some carbide forming elements (e.g., Cr, Mo, and V) are enriched in the carbide particles formed in 750 °C tempering while Fe is depleted in the particles. Ni shows no visible partitioning after tempering. This confirms the result of thermodynamic calculation that Cr20Mo3C6 is the most common carbide composition in the tempered HT-9 steels. The analysis will be continued for the macrostructures formed in the processing routes between these two extreme (non-tempered and fully tempered) conditions, and the final set of microscopy data will be used for selecting TMP conditions for high fracture toughness. (T.S. Byun)

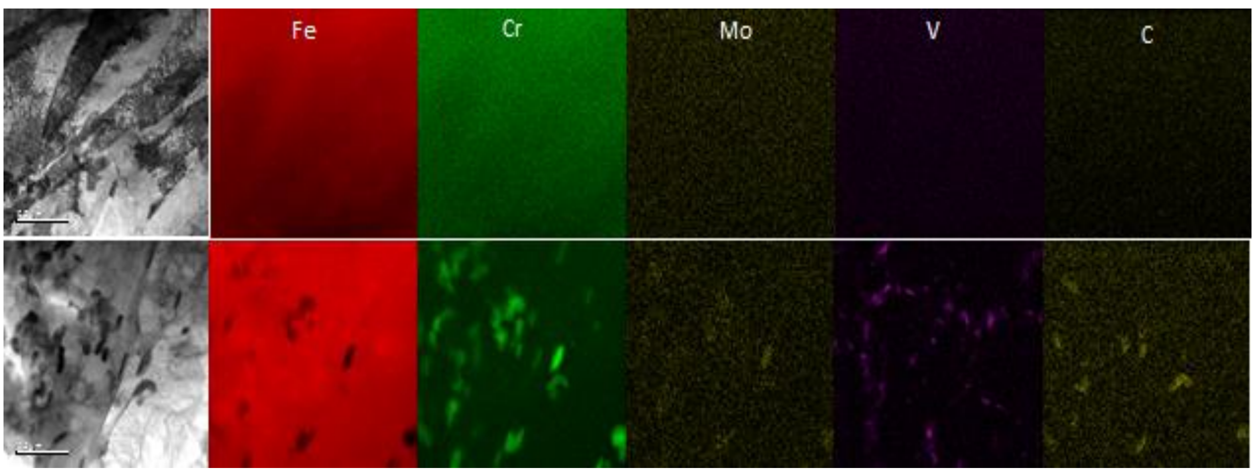


Figure 7. STEM-EDS maps of HT-9 steels in as-quenched condition (upper raw) and in quenched and 750°C tempered condition (lower raw). Shown in the far left images of upper and lower rows are corresponding bright field TEM images.

AR Irradiation Testing & PIE Techniques

- **[ANL]** Simulations were continued of the annular fuel behavior in the Advanced Burner Test Reactor (ABTR) using the SSCOMP-A module that was extended for the analysis of annular metal fuel pins. The results illustrated in Figures 8 and 9 indicate that the geometry of the central hole and the probable fuel melting pattern during a postulated accident can change significantly during the irradiation. Figure 8 shows the annular fuel behavior at an early burnup stage (BU=0.70%). The central hole is still open, but significant swelling of the fuel and reduction of the central hole diameter is observed in the upper half of the fuel pin. Figure 9 shows the behavior at burnup of BU= 2.61%. The upper part of the central hole closes gradually, preventing direct communication of the remaining lower part of the central hole with the pin upper plenum. Fuel melting is likely to lead to the formation of an annular molten cavity, which is likely to communicate with the lower part of the central hole, allowing the molten fuel from the cavity to drain and relocate downwards into the remaining central hole. These preliminary results provide valuable guidance for the planning of the molten fuel relocation model extensions. (T. Kim)

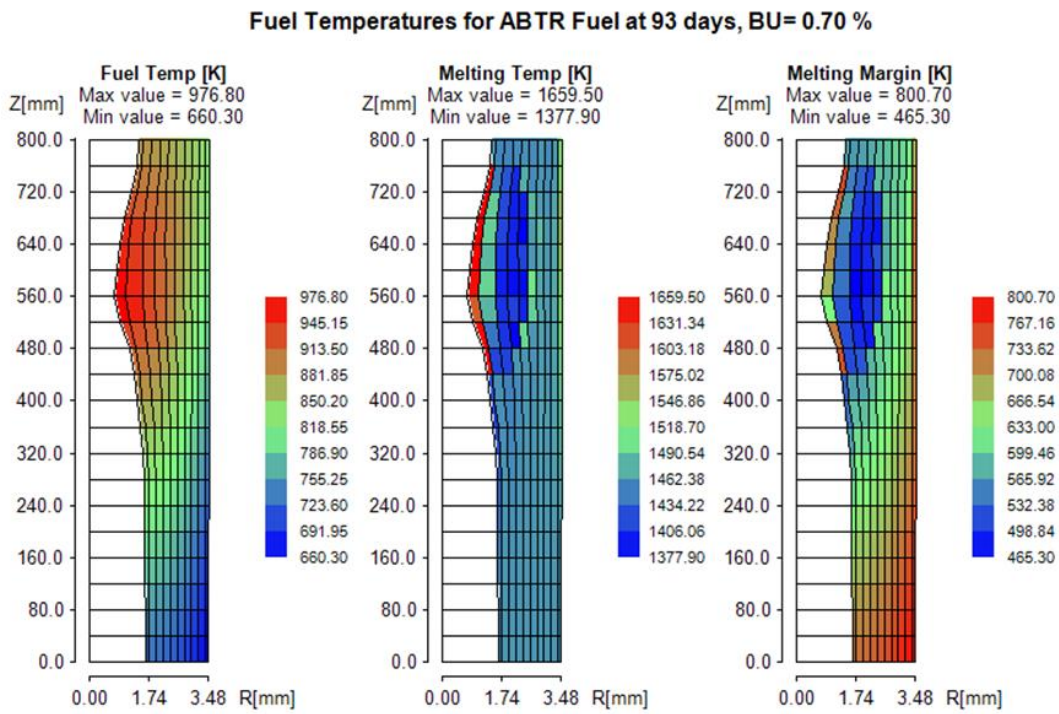


Figure 8. Geometry of the fuel pin and margin to melting distribution at max BU=0.70%.

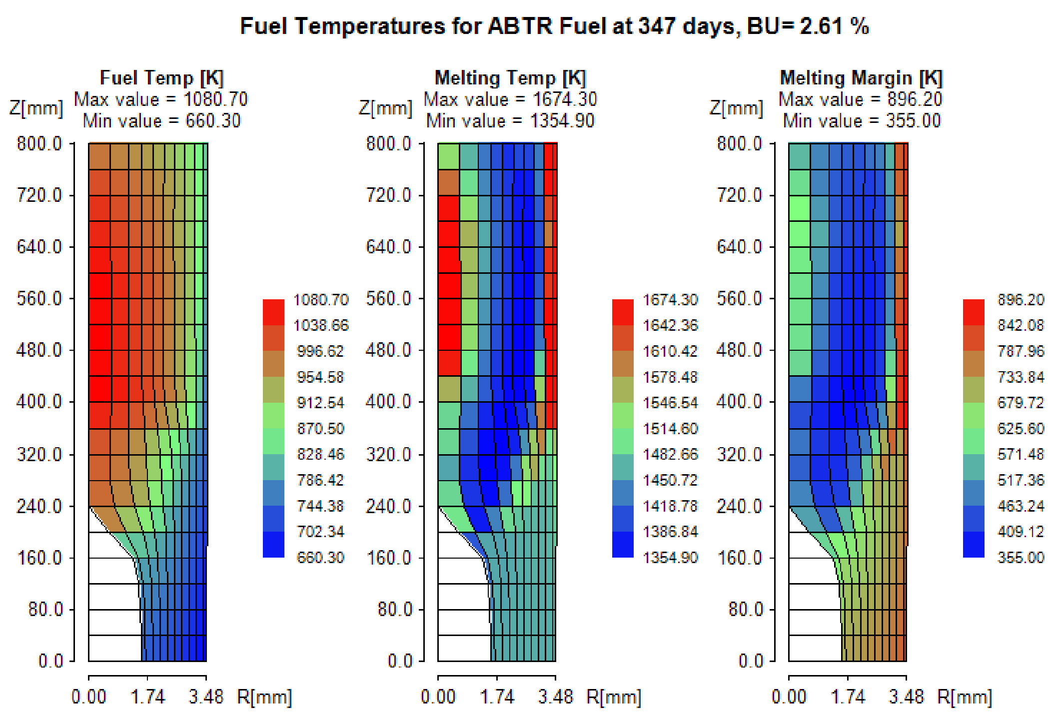


Figure 9. Geometry of the fuel pin and margin to melting distribution at max BU=2.61%.

- **[INL]** Cycle analysis, experiment reconfiguration, and experiment insertion into the ATR for cycle 162B-1 were all completed in time to support an early ATR cycle startup date (12 days early). (D. Dempsey)
- **[INL]** Fission Gas Release measurements were initiated on the AFC-3C and AFC-3D rodlets. The initial results from this should be available next reporting period. (J. Harp)
- **[INL]** Scanning Electron microscopy was performed on a sample of irradiated annular U-10Zr, 55% smear density helium bonded (AFC-3A R4). With this exam it was possible to confirm the chemical microstructure of this sample which is notable for the large amount of Zr redistribution that occurred in the fuel pin. Zr redistribution resulted in the annular hole closing and the depletion of Zr in the outer radius region of the fuel. The Zr depleted U appears to have reacted with the cladding to some degree. A montage of backscatter electron images is shown in Figure 10. The data from this exam should be useful for the validation of Zr redistribution models. (J. Harp)

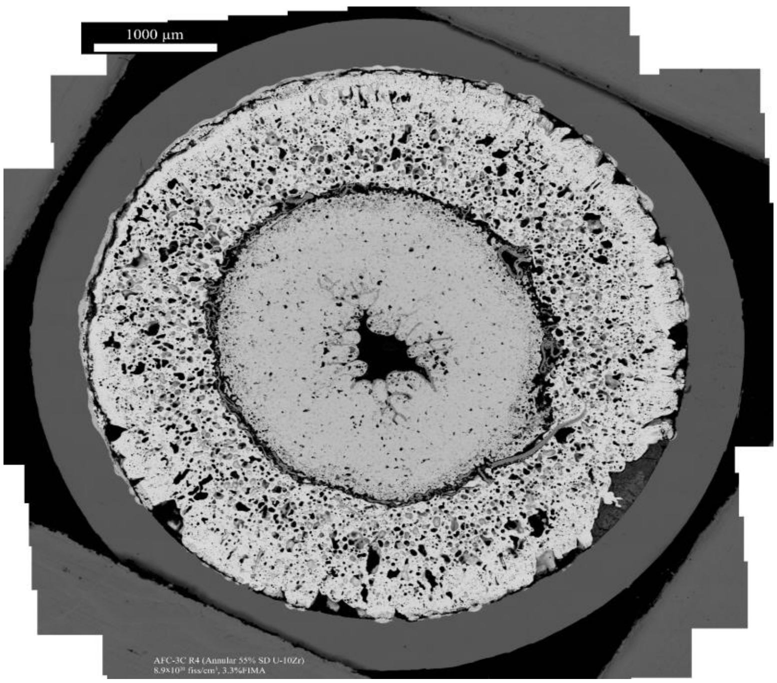


Figure 10. Montage of backscatter electron images.

AR Fuel Safety Testing

- **[INL]** A literature review was continued. There is now a substantial collection of historical fuel performance, metal fuel qualification and testing plans, and relevant regulatory documents. A draft review manuscript was begun, to serve as initial component of year-end milestone. (D. Wachs)

AR Computational Analysis & Fuel Modeling

- **[INL]** A paper titled, "Modeling porosity migration in LWR and fast MOX fuel using the finite element method," was submitted to the *Journal of Nuclear Materials*. In the paper, an engineering scale finite element simulation of pore migration in oxide fuel is presented. The porosity field is governed by an advection-diffusion equation which is coupled to the fuel temperature and stress fields through the thermal conductivity and volumetric heat source term. The engineering scale porosity equation models the microscopic process of vapor transport of fuel across pores, taking into account thermal and vapor pressure gradients within the fuel. In the simulations, the porosity is initialized to a constant value at every point in the domain, and as the temperature gradient is increased by application of a heat source, the pores move up the thermal gradient and accumulate at the center of the fuel in a time frame that is consistent with experimental observations. Results from representative simulations are provided to demonstrate the new capability, and we show that a sufficiently high power ramp rate limits restructuring and leads to a corresponding increase in fuel temperature. We also discuss the finite element mesh density required to compute pore migration and present multidimensional results. (P. Medvedev)

- **[LANL]** The mechanistic swelling model was implemented in ABAQUS and is being tested at an element level. This includes both the stress update and the tangent modulus which is derived using the bubble equilibrium equation. The tangent includes both the effect of swelling and the change in material stiffness due to porosity which serves as a first order model to include damage. Single element tests show reasonable results for increase in porosity with time. (C. Unal)
- **[LANL]** The initial MCNP burn run completed for one fuel pin model, which shows burnup impacts at various time steps and changes to fission rate throughout fuel pin. Future work will incorporate this burnup into the power fraction model. (C. Unal)

CAPABILITY DEVELOPMENT

CX Fuels

- **[INL]** A glove box compatible sputter coater has been identified but not yet ordered. Most of the work this month has centered on an indexing system for the TCM furnace. The current furnace required an indexing method to allow for consistent mounting on the TCM sample stage. The furnace also required modification for use with remote manipulators. A new furnace base has been designed which will index with the existing TCM sample stage. A new lid base and lid top that are compatible with the IMCL TCP remote manipulators have also been designed. These will be fabricated and tested in the coming weeks. Software improvements are also progressing. (D. Hurley)

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

MATERIAL RECOVERY AND WASTE FORMS DEVELOPMENT

PROCESS CHEMISTRY AND INTEGRATION

- **[INL]** The level four milestone (M4NT-18IN030102011) titled, "Analysis of FY17 ALSEP Samples," has been completed. The variation of the composition of the ALSEP solvent samples generated during FY-2017 has been determined. This report describes the results of gas chromatography (GC), high performance liquid chromatography (HPLC), ion chromatography (IC) and inductively coupled plasma – optical emission spectroscopy (ICP-OES) analytical techniques employed to analyze aqueous and organic samples taken from INL's acid only, simulated ALSEP feed, and ALSEP scrub solution test loop radiolysis experiments performed during FY-2017. (D. Peterman)
- **[INL]** The analysis of the irradiated aqueous and organic samples taken from the test loop radiolysis experiments demonstrated that the gamma radiolysis does result in the loss of the 2-ethylhexylphosphonic acid mono-2-ethylhexyl ester (HEH[EHP]) and N,N,N',N'-tetra(2-ethylhexyl)diglycolamide (T2EHDGA) extractants. The extent of degradation observed would not lead to any concerns regarding the ability of the ALSEP solvent to perform adequately for reasonable absorbed gamma dose scenarios. (D. Peterman)
- **[INL]** The radiolytic degradation of HEH [EHP] does result in the formation of 2-ethylhexylphosphonic acid (the main degradation product formed). This degradation product adversely impacted stripping of americium from the loaded ALSEP solvent. This adverse impact should be addressed by the development of an effective solvent washing system which removes radiolytic degradation products from the irradiated solvent. INL is currently tasked with the development of a suitable ALSEP solvent washing system. (D. Peterman)
- **[ORNL]** Evaluation of several improved LTA tubular zeolite membranes recently prepared for evaluations of tritiated water concentration was begun. A preliminary experiment was performed with tritiated water feed solution using the LTA membrane synthesized on a Ceramic support (Sample M1). Due to the low permeance, a substantially concentrated retentate was not obtained after a 7-hour run. We plan to carry out a longer duration experiment to obtain a more concentrated retentate and will report the results in the next monthly report. (B. Jubin)
- **[ORNL]** As mentioned in the last monthly report, a third larger pellet was pressed using a 41mm die at the same mixing ratio 40v% WO_3 and 60v% Cu with a sintered volume of ~20mL. The results were very similar to the smaller pellets. Figure 1 shows the green pellet with a green density of 63% of the theoretical density (TD); Figure 2 shows the pellet after sintering for six hours at 900^{o}C with a density of 92% of the TD. After sintering, the larger pellet had an incipient hour-glass shape. The pellet was cut in half and the surface polished. Overall the pellet appeared very uniform. There are some voids that may be real or an artifact due to the removal of particles during the cutting and polishing. As the sintered density was 92% of the TD, the overall void space is very limited. As mentioned in the January report, a surrogate UNF powder was prepared by ammonia precipitation. The ammonium diuranate was dried and calcined to produce a solid solution of the simulated fission products in the UO_3 matrix. The surrogate powder was then mixed with copper powder using the same volumetric mixing ratio 40v% UO_3 and 60v% Cu. Afterward, six green pellets were pressed using a 1"die and are in the process of being sintered. (B. Jubin)

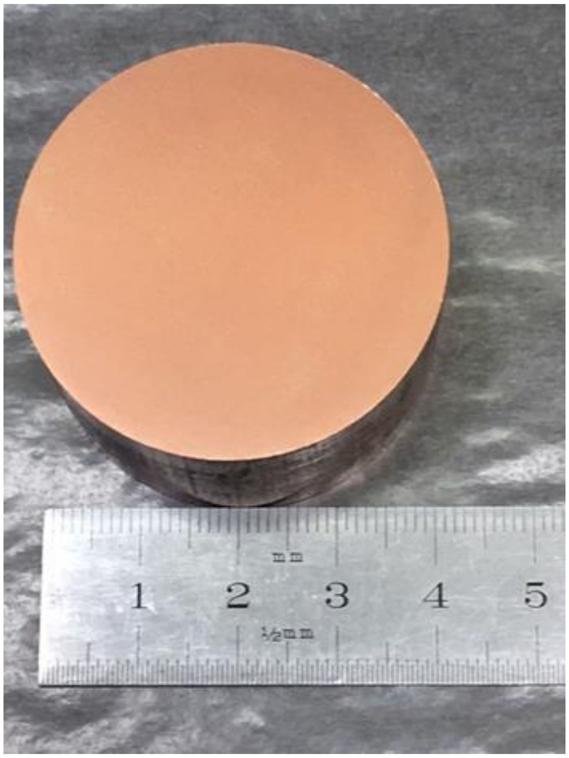


Figure 11. 41 mm diameter green pellet.

Figure 12. Pellet after sintering for six hours at 900°C.

- **[ORNL]** G. DelCul will be traveling to France to attend the OECD/NEA Expert Group meeting on Progress in Separation Chemistry (B. Jubin)

WASTE FORM DEVELOPMENT AND PERFORMANCE

Electrochemical Waste Forms

- **[ANL]** Minor modifications to the suite of materials called for in the test plan were discussed with colleagues based on analyses of the first material that was made (DPF1). It was agreed that a material with a lower salt loading suggested by B. Riley would provide useful insight regarding the effect of salt loading. (W. Ebert)
- **[PNNL]** Experiments were completed to dechlorinate an electrochemical salt simulant (ERV2) using $NH_4H_2PO_4$ at different ratios of $NH_4H_2PO_4$:ERV2. The products of these reactions at temperatures of 100–600°C were NH_4Cl (recovered as a solid condensate and confirmed with X-ray diffraction), water, acids (HCl, HI), and condensed iodine vapors. The solid condensate products were shipped to INL for chemical analysis from the 5 experiments (DPF-1, -2, -3, -4, and -5) outlined in the FY17 test plan (NTRD-MRWFD-2017-000191) as well as an additional experiment (DPF-6) with a lower salt loading than the previous batches. The liquid condensates recovered during the experiments were also sent to INL for chemical analysis. (B. Riley)

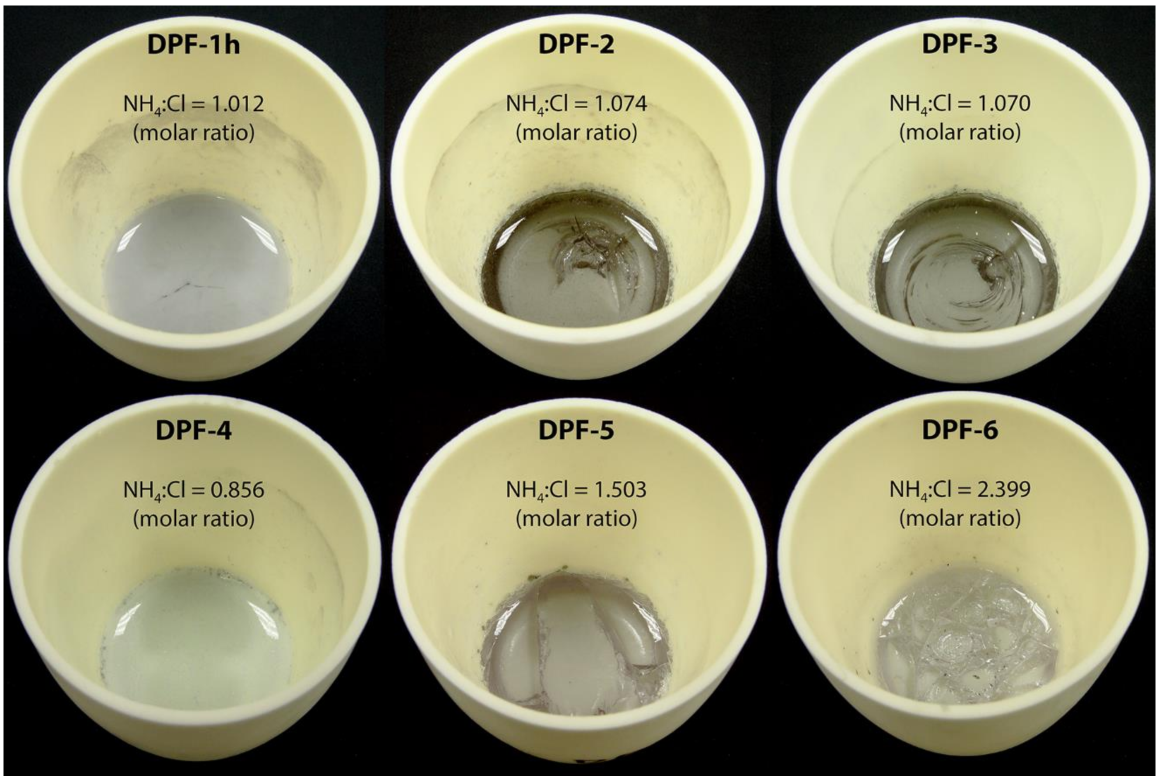


Figure 13. Optical collage of crucibles with products following dechlorination procedures.

Glass Ceramics Waste Forms

- **[LANL]** Radiation-induced volume change in glass ceramic waste form materials (reminder glass, single phase oxyapatite, single phase powellite) was investigated using ion irradiation and atomic force microscopy (AFM) techniques. Ion irradiation was performed using 195 keV He ion at room temperature to simulate alpha radiation damage. In this study, part of the surface regions for each sample was covered by aluminum foil to block from ion beam irradiation to allow the characterization of irradiation-induced volume change. The surface morphology and the interface between the unirradiated and irradiated regions were characterized by AFM. Figure 14 shows 2D and 3D AFM images of the irradiated and unirradiated region of (a) reminder glass, (b) oxyapatite, and (c) powellite.

(a)

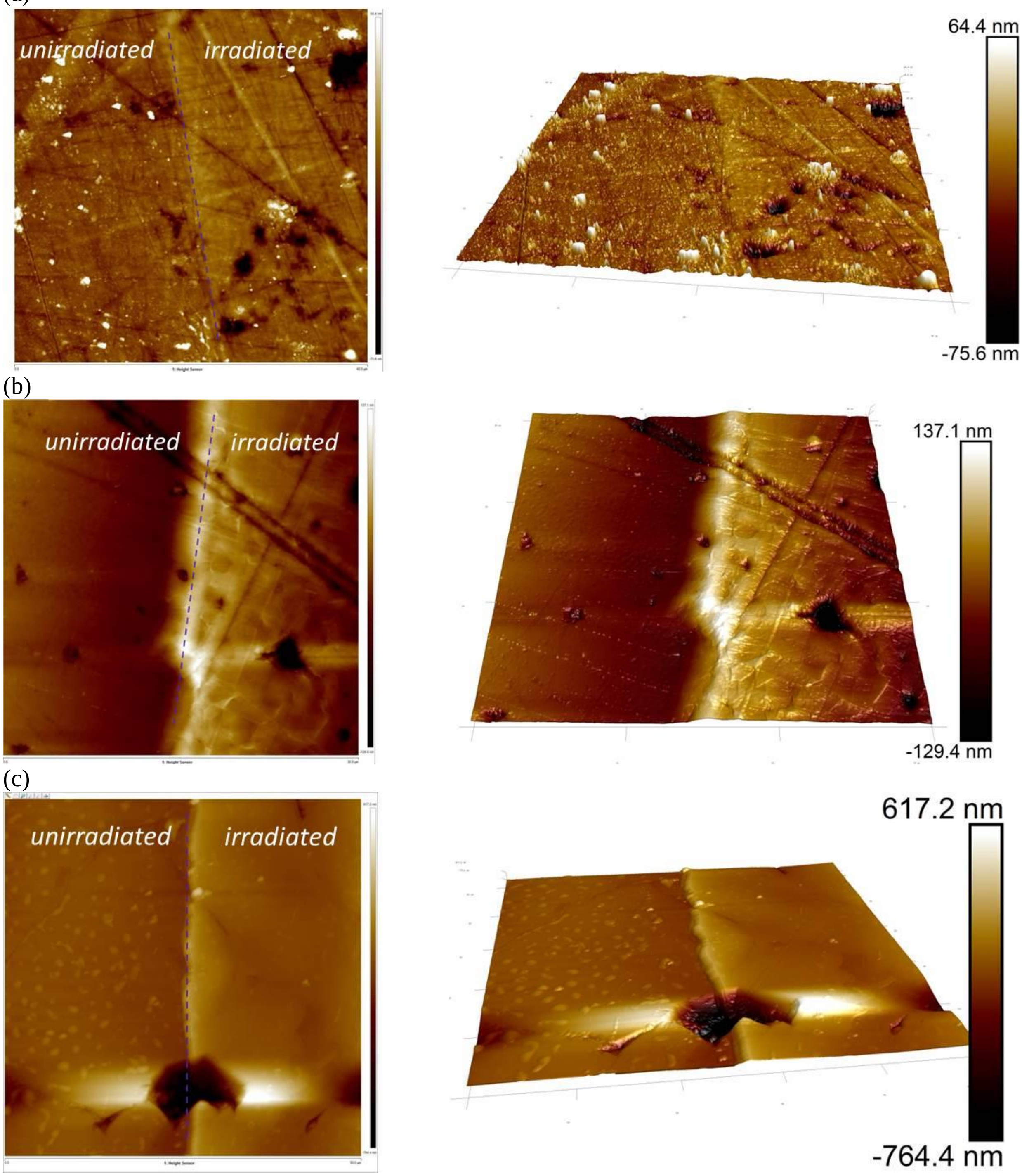
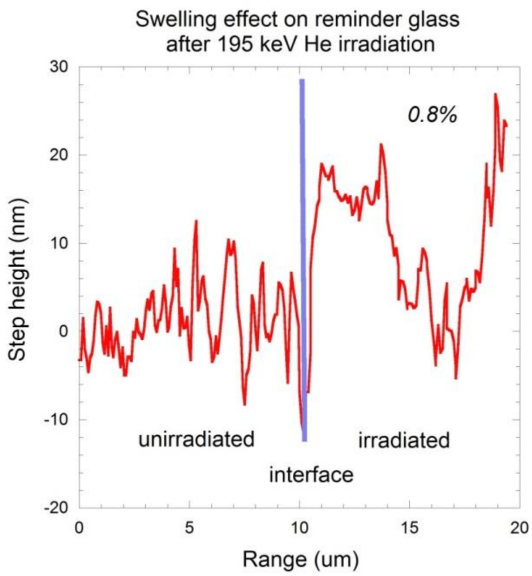


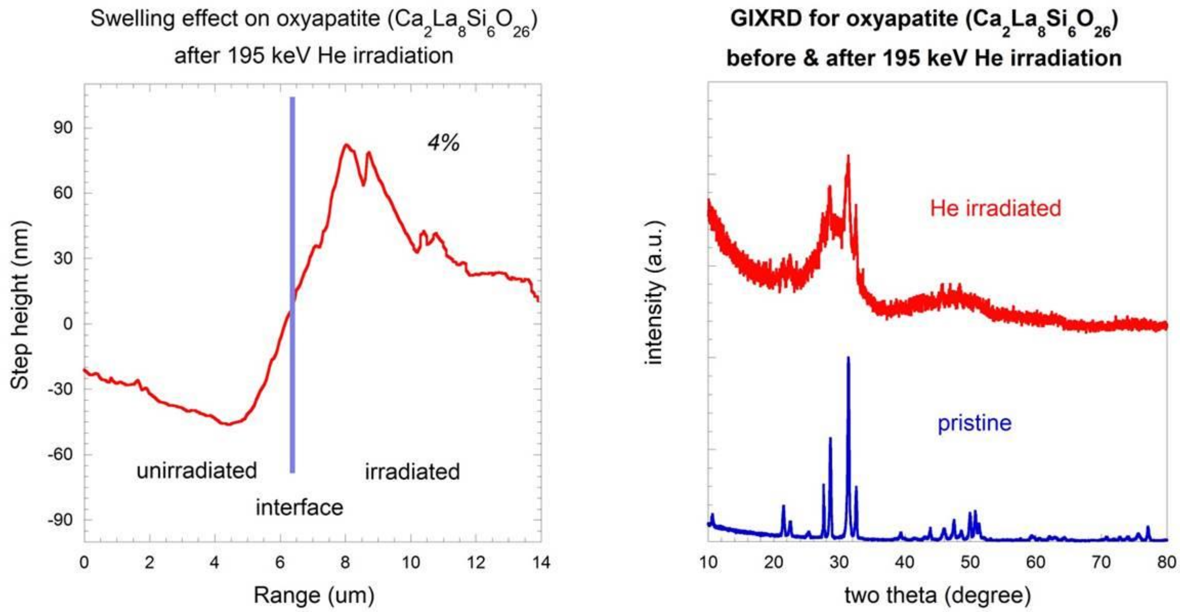
Figure 14. 2D and 3D AFM images of the irradiated and unirradiated regions of (a) reminder glass, (b) oxyapatite, and (c) powellite.

Figure 15 shows the measured step heights obtained from the line scans in AFM observation, swelling or compaction percentage is calculated using height change compared with ion irradiation range, (a) reminder glass, (b) oxyapatite, and (c) powellite. XRD results of oxyapatite and powellite before and after He irradiation are included in (b) and (c). Based on the observation of these two samples, the preliminary results reveal different swelling & compaction in different crystalline phases and glass. The calculated volume change in oxyapatite is up to 4%, and this is consistence with radiation induced amorphization in oxyapatite (see XRD in Figure 15(b)). For irradiated powellite phase, the volume change is less than ±0.1% and no obvious crystal structure change in this phase after He irradiation. Experimental results reveal that the swelling in crystalline phases of glass ceramic waste forms is related to microstructural evolution under radiation damage. For reminder glass, the volume change under ion irradiation is very close to that under neutron radiation or actinides doping conditions. Further characterizations on multiphase glass ceramics are in progress in order to interpret radiation-induced volume change.

(a)



(b)



(c)

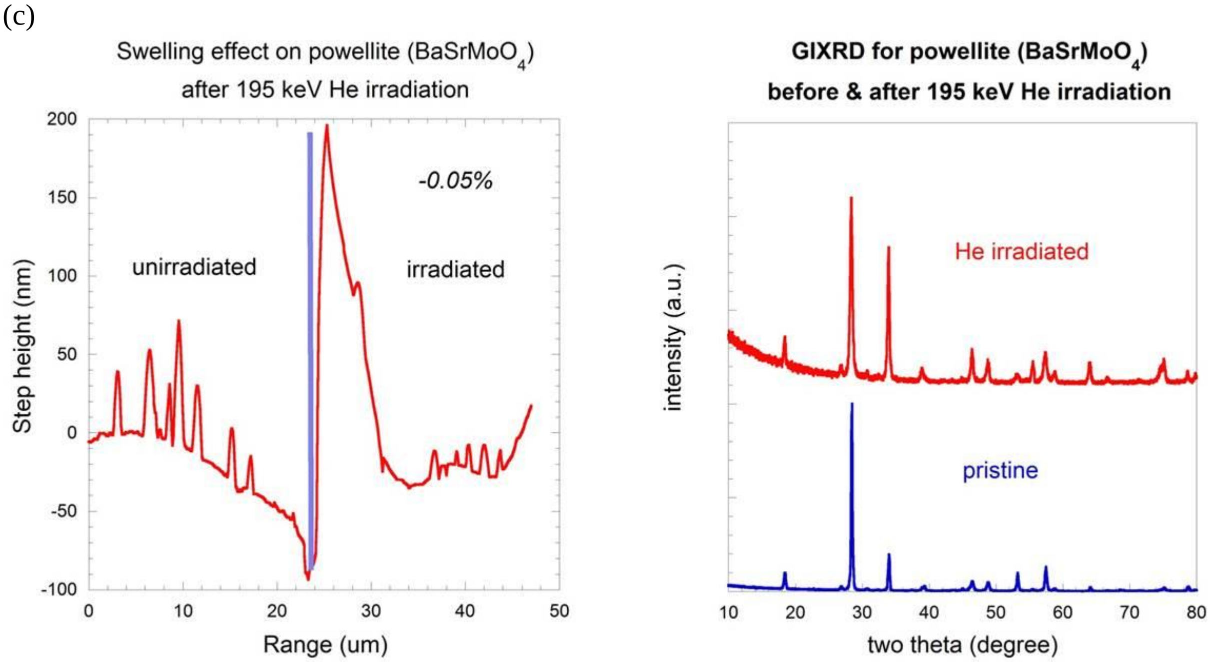


Figure 15. Measured step heights obtained from the line scans in AFM observation, swelling or compaction percentage is calculated, (a) reminder glass, (b) oxyapatite, (c) powellite. XRD results of oxyapatite and powellite before and after He irradiation are included.

- **[PNNL]** A journal article was prepared that discusses a novel method to synthesize phase pure $Nd_3BSi_2O_{10}$ structure (Figure 16) using LiCl flux that will be submitted to the *Journal of Nuclear Materials* in March 2018. This phase is one of the major crystalline phases observed in the glass-ceramic waste form and is projected to host a large fraction of the lanthanides and actinides present in a typical high-level waste raffinate stream. For this reason, it was synthesized and the corrosion behavior was measured in dilute conditions at 90°C and buffered pH to determine its benefit or hindrance to the glass-ceramic waste form performance. The measured release rates (see Figure 17) of Nd from this structure in dilute conditions at 90°C are orders of magnitude slower than the glass (matrix phase) found in the glass-ceramic waste form. The crystal is only sparsely soluble in basic conditions, typical in a geological repository. These results confirm $Nd_3BSi_2O_{10}$ is a chemically stable host for lanthanide and actinide fission products that benefits the overall chemical durability of the glass-ceramic waste form. (J. Crum)

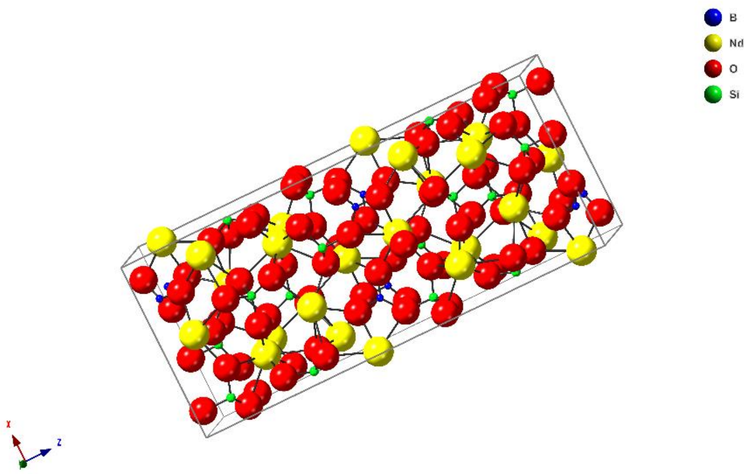


Figure 16. $Nd_3BSi_2O_{10}$ Ball-Stick Structure

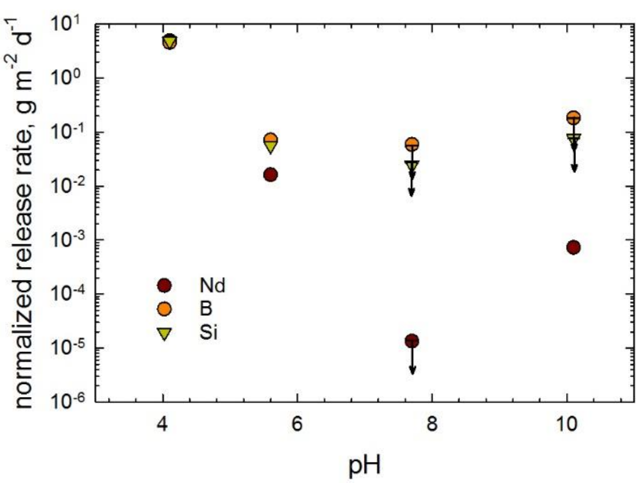


Figure 17. Normalized release rates of Nd, B, and Si form $Nd_3BSi_2O_{10}$ phase in dilution conditions at 90°C

Zirconium Recycle

- **[ORNL]** The glovebox at building 3525 that has been selected for the purification tests will need modification to provide the necessary utilities for the operations (e.g., argon supply line, electrical receptacles, thermocouple connections) and will be installed by the hot cell facility operations personnel. Research Safety Summaries for Buildings 3525 and 4501 are being revised to incorporate updates needed for the project. Planning is underway for performing initial (cold) testing operations in a fume hood at Building 4501. (B. Jubin)

Advanced Waste Form Characterization

- **[ANL]** Construction of the Ar-atmosphere glovebox was completed and shake-down tests have been performed (Figure 18). The apparatus provides a low O_2 atmosphere to allow for chemical control of the solution redox using various buffers. Initial tests use a saturated $FeSO_4$ solution to provide reducing conditions at mildly acid and near-neutral pH values. Future tests will use magnetite to provide reducing conditions at alkaline pH values. Experiments will be conducted to compare AgI dissolution rates measured under chemically-controlled conditions with rates measured previously under conditions controlled using a potentiostat. Subsequent experiments will be conducted to measure the dissolution rates of AgI powder and AgI-bearing composites under the same conditions. (W. Ebert)

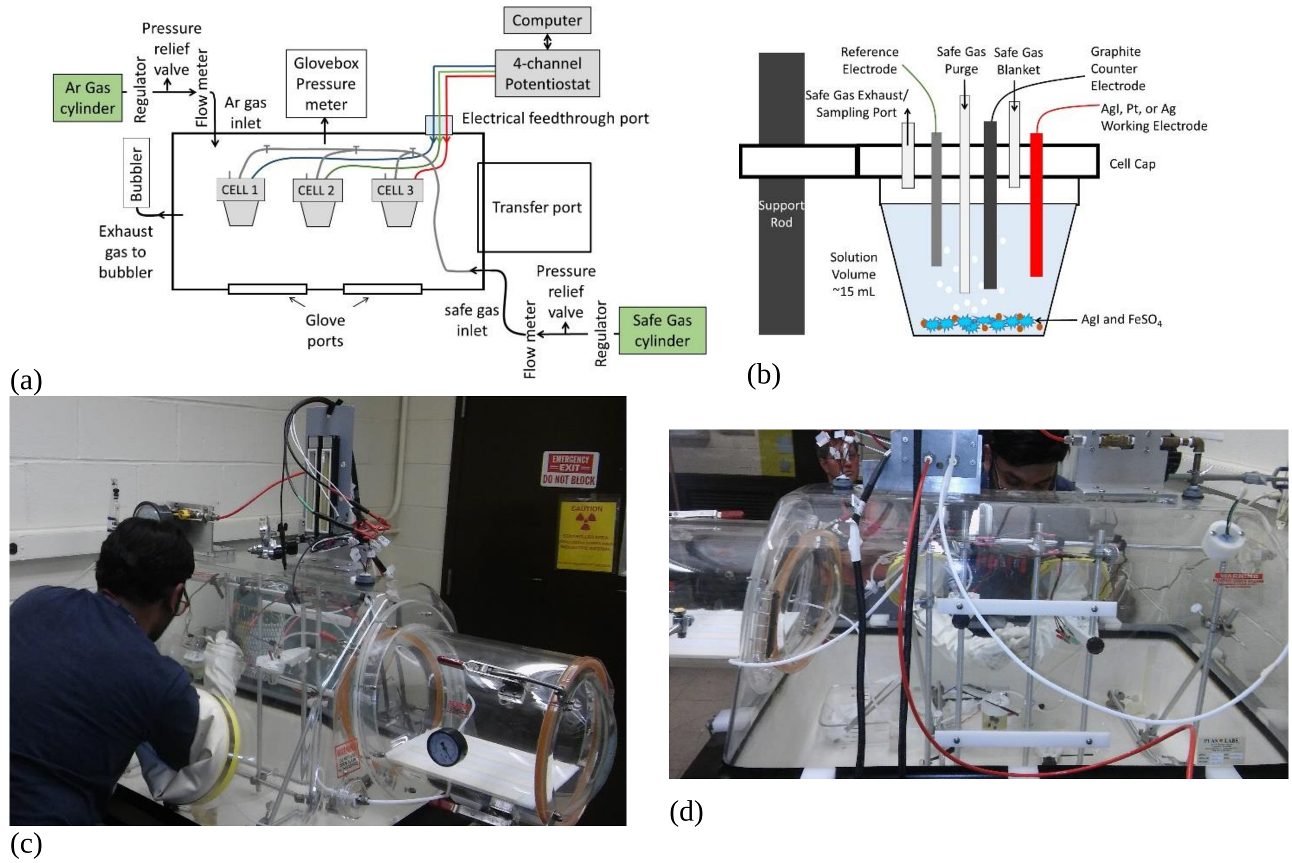


Figure 18. Schematic drawings of (a) glovebox design and (c) electrochemical cell design and photographs of V.K. Gattu preparing an experiment from (c) the glove port side and (d) the back side of the glovebox.

- **[PNNL]** Ongoing tests to evaluate the propensity of Stage III (delayed acceleration) corrosion behavior for various glass compositions have shown significant preliminary results. Previously, we showed the first direct evidence of Stage III behavior at temperatures lower than 90°C when the acceleration was observed for a low-activity waste glass composition at 70°C. This result has now been confirmed for HLW glass compositions as well. For tests at 70°C and seeded with zeolite P2, a definite signal was observed for the SRNL-202 glass composition and a lesser, but still measurable, effect was observed for the SON68 glass composition. Interestingly, after a brief increase in rate, the SON68 glass appeared to slow to a near residual-rate corrosion condition. Considering the relatively low pH of this system compared to others that have exhibited Stage III behavior, we believe that there might be a system pH below which Stage III behavior (likely zeolite growth) is not sustainable. A longer dataset may provide more insight into these phenomena. Long-term tests at 40°C and 25°C for both compositions were seeded in February, with data expected on those conditions by the end of the fiscal year. Similar experiments on the AFCI composition are delayed from the other two by approximately 6 months, but are also ongoing. (J. Ryan)

DOMESTIC ELECTROCHEMICAL PROCESSING

- **[ANL]** Two reports were drafted and technical reviews completed. One report summarizes the results of reviewing unpublished monthly technical reports from previous projects dating back about 18 years to add insights regarding the chemistry of Zr in molten salt systems. The review indicates a non-volatile compound probably forms that sequesters Zr and mitigates volatilization of $ZrCl_4$. Minor revision of that report is in progress. The other report summarizes the operational approach for U/TRU co-deposition, the software used to control operation, and how the operator can maintain optimal conditions during the operation. Revision to add figures to support the text is in progress. (W. Ebert)

SIGMA TEAM FOR OFF-GAS

- **[INL]** A test of iodobutane adsorption using silver zeolite sorbent was started in early December and completed in February. A goal of this test, which was to operate long enough to reach practical saturation levels in at least the shallow (0.5-in. deep) Bed 1, appears to have been accomplished. Sorbent samples from all four beds used in series during this test will be analyzed for iodine and silver content compared to the original sorbent.

  An additional iodobutane adsorption test was initiated during the week of February 26. The moisture content was increased to provide a water dewpoint of about 20°C, representative of the dewpoint for a typical vessel off-gas stream at about 20°C. (N. Soelberg)

- **[INL]** The Level 4 Milestone M4NT-18IN030107016, titled “Test plan for long-chain iodine VOG testing,” was completed on February 28, 2018. This milestone was for INL’s support to ORNL to meet the ORNL milestone for this test plan. (N. Soelberg)

- **[ORNL]** Testing associated with the milestone, “Complete testing of integrated iodine scrubber and polishing bed system,” has required system upgrades of the NO_2 delivery system. System upgrades are nearing completion, with the final outstanding items including revision of the safety basis and completion of the control system. The LiCor instrument intended for online CO_2 measurement has been received. The scrubber and gas feed system are assembled. Basic testing has been performed to identify initial operating parameters; further refinement of these parameters (such as the liquid to gas (L/G) ratio) are included in the test plan and will depend on results obtained from the CO_2 testing. (B. Jubin)

- **[ORNL]** The experimental test for the task, “Evaluate the results of extended duration test of VOG sorbents to support the determination of key engineering parameters,” was terminated after 8 months in operation. The material was removed from the bed and is awaiting analysis (B. Jubin)

- **[ORNL]** The milestone titled, “Evaluate the iodine retention of long-chain organic iodides on both AgZ and AgAerogel over the range of expected concentrations in both the DOG and VOG systems and issue joint ORNL/INL report,” was completed on February 28, 2018 with the issuance of a test plan authored by both ORNL and INL. The objective of this test plan is to lay out a robust experimental program that will evaluate the adsorption rate of long chain organic iodides and identify any significant variations in mass transfer zone and by-products produced during the adsorption on AgZ and AgAerogel under both dissolver off-gas (DOG) and vessel off-gas (VOG) conditions expected for a used nuclear fuel (UNF) aqueous reprocessing facility. Organic species of interest include both short chain alkyl iodides such as methyl iodide (CH_3I) and longer alkyl iodides up to iodododecane ($C_{10}H_{21}I$). The plan describes experimental work that could be conducted as part of the on-going off-gas abatement R&D efforts at both INL and at ORNL. It identifies a series of outstanding questions that apply to both DOG and VOG conditions and lays out a series of high level, inter-related tests that would seek to provide insight into these questions. (B. Jubin)

- **[ORNL]** Progress continues on the task to complete the initial series of Ru adsorption optimization studies and provide recommended changes to the assumptions used in the analysis of an integrated off-gas systems. Materials to build glass columns with stainless steel screens for deposition surfaces were received, and the fabrication of other system components was completed. The completion of this milestone will depend on the timeframe in which the sample analysis can be completed. Sample analysis is performed at ORNL by the Chemical Sciences Division. (B. Jubin)
- **[ORNL]** A detailed experimental test plan was developed for the task to quantify the potential physisorption on silver based sorbents that were potentially observed in FY-17 VOG testing. A test examining the potential physisorption of CH_3I by AgZ with CH_3I concentrations of 200 ppb was completed and the sorbent has been sent for analysis to determine iodine content. A second test examining the adsorption of I_2 by AgZ at I_2 concentration of 100 ppb has been initiated. (B. Jubin)
- **[PNNL]** The recent publication from Pacific Northwest National laboratory showcases the separation and storage of Xenon from various class of adsorbents were reported in *Chem*, 4, 466-494, 2018. This article particularly highlights the various adsorbent materials tested thus far under DOE NE Fuel Cycle Research and Development program for separation Xenon at room temperature as opposed to cryogenic distillation. *Chem* is a sister journal to *Cell*, provides a home for seminal and insightful research and showcases how fundamental studies in chemistry and its sub-disciplines. This work was highlighted within in PNNL and also highlighted internally at PNNL by Dr. Steve Ashby, the director of the laboratory, in his speech to senior laboratory management. (P. Thallapally)
  - **https://www.youtube.com/watch?v=riID7v0zLdQ**
  - **https://www.pnnl.gov/news/release.aspx?id=4490**

FLOWSHEET DEMONSTRATIONS

- **[ANL]** Evaluation of the results of the first CoDCon demo test at PNNL continues using the AMUSE code. As the initial runs suggested, a higher U:Pu ratio would be expected than was observed given the operating conditions. A number of additional runs were done as part of a parametric analysis to bracket the expected performance based on the process models. The major cause of the differences was a higher than predicted U(IV) D-value. All of the other D-values were relatively consistent with the reported distributions, even as parameters were adjusted. The U(IV) model was reevaluated, but was found to be essentially accurate based on the reference data. (C. Pereira)

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

MPACT Campaign

MANAGEMENT AND INTEGRATION

Management and Integration

- **[INL]** Coordinated planning of Spring WGM, to be held at INL, March 20-22, 2018. Hosted Mark Croce (LANL) for discussions on calorimetry testing at INL as part of JFCS, and possible microcalorimeter testing.

SAFEGUARDS AND SECURITY BY DESIGN - ECHEM

Voltammetry

- **[ANL]** Installation of wiring and transfer of the voltammetry sensor into the glovebox have been completed. Initial measurements using the sensor are to be made in the coming days, in preparation for the MPACT Workgroup meeting in mid-March. New simulations capable of accounting for large inductance effects have been produced in order to ensure the accuracy of the electroanalytical measurements at engineering and industrial scales.
- **[INL]** The engineering voltammetry probe was successfully fabricated. This probe includes a platinum wire electrode, a tungsten wire electrode and two Ni/NiO reference electrodes. The dimension of the probe is the same as the probe to be tested in Integrated Recycling Test (IRT) Oxide Reduction (OR) furnace. Currently, the newly fabricated engineering probe is immersed in pure LiCl salt and is ready for cyclic voltammetry (CV) measurements in the Engineering Development Laboratory (EDL). CVs will be performed in LiCl salt with 0, 0.25, 0.75, 1.0wt% Li2O concentrations, and then followed by CV measurements of La2O3 and Nd2O3 in LiCl-1% Li2O with incremental additions of GdCl3 (oxidizer).

Sensor for Measuring Density and Depth of Molten Salt

- **[INL]** Data obtained from calibration and validation experiments during the past two months has been analyzed, and an internal report was generated. These experiments (without salt additions) have demonstrated that the bubbler is stable and functions as designed. In addition, the governing equations appear to be correct.

Electrochemical Signatures Development

- [LANL] Development of animated movies depicting radiation behavior for MCNP6 moving-object radiation mesh-tally data using gnuplot and GIMP continued. The models include the High Dose Neutron Detector (HDND) model in concert with the 252Cf and 137Cs sources that are being used for detector design and operation studies during FY18. During January, the MCNP6 simulations and movies depicted time-evolving neutron and gamma radiation fields within the test room using a perfectly absorbing boundary. During February, the models were adjusted to include the use of nominal concrete wall properties so as to illustrate the radiation field inclusive of scatter from the walls. The movie images suggested an error in the MCNP6 models. Upon examination, the MCNP6 simulations showed erroneous radiation behavior that extended beyond the boundaries of the facility wall. The models were stipulated to terminate particle transport outside the wall (imp: n,p =0, i.e., a zero-flux boundary condition). The MCNP6 input files were modified so that each calculation used a moving source during a stipulated time window, and the time-segmented mesh tally was disabled. After the fix was implemented, the 252Cf and 137Cs models were executed using 100 input files (apiece) for a sequence of source time increments of 1/100th of the total elapsed time of source movement and without time-segmented mesh tallies. Simulations were executed with and without wall properties. Movies for each model were then created using gnuplot and GIMP for linear and logarithmic scales in the mesh-tally radiation data. Subsequent to the input file modifications, the mesh tally showed the desired absence of radiation beyond the wall. Moreover, the pre-fix odd mesh-tally structure within the facility was no longer apparent. For moving-objects simulations, time-segmented mesh tallies thus seem to be applicable for times between the start and end times of source particle emission. At present there is no means of automatically inputting the MCNP geometry into gnuplots. Gnuplot geometries for the 252Cf and 137Cs models and the pyrofacility models were developed. Preparation of the gnuplot .plt files was automated via the creation of gnup.f, which including all of the .plt file instructions for each mesh tally. In summary, capability has been created to produce movies of simulated time-evolving neutron or photon radiation fields within a facility that have been calculated using the MCNP6 moving-object feature. All effort is detailed in the FY18 OUO summary report, “Calculation of Time-Dependent Radiation Signatures for Electrochemical Reprocessing Using MCNP6 Moving Objects FY18 Interim Summary Report in Support of MPACT”.

Advanced Integration

Advanced Integration (Methods)

- **[LANL]** A comprehensive picture of Microcal Pd's and facility integration was completed.

Advanced Integration (Facility Models)

- [SNL] Engaged with ANL, LANL, and INL to integrate efforts to demonstrate electrochemical safeguards and security by design. The SSPM will be updated with the current flowsheet from ANL.

Exploratory Research / Field Tests

Microcalorimetry

- **[LANL]** Completed M3 milestone, "Demonstrate reliable, high-resolution gamma spectroscopy with microwave readout" on schedule, and submitted report. While we have made significant progress towards reliable operation, development work is needed to decrease user involvement prior to deploying an instrument for field testing. Work and equipment upgrades originally planned for February were not fully completed due to personnel limitations, but we expect to catch up by the April-May timeframe. This will involve upgrades to the room temperature readout electronics and streamlining the data pipeline from raw data to spectra. Katrina Koehler is continuing work on modeling of electron-capture spectra, and began a measurement campaign to collect data on Pt-193 with which to validate her theoretical models.

In situ Measurement of Pu Content in U/TRU Ingot

- **[INL]** With continued delays at window 10M in the Hot Fuel Examination Facility (HFEF) related to the casting of JFCS products, alternative locations for performing U/TRU melting point tests were investigated. Window 11M in HFEF was selected based on the availability of thermocouple and power requirements. The furnace for melting the fourth JFCS U/TRU product was transferred into HFEF and cooling curve analyses will commence following the in-cell qualification of the furnace.

High Dose Neutron Detector

- [LANL] All three HDND detectors along with associated cabling were shipped to INL for installation. Post-transportation functionality evaluation at INL is planned during the upcoming

MPACT working group meeting in March. Pending facility safety reviews, the start of field test is scheduled for early April.

For more information on MPACT contact Mike Miller at (208) 526-2813.

Fuel Cycle Options Campaign

CAMPAIGN MANAGEMENT

- **[ANL]** Participated in the DOE NE-4 Steering Committee Meeting with the Fast Reactor, Gas Cooled Reactor, and Molten Salt Reactor Campaigns in Washington D.C., February 1, 2018.
- **[ANL]** Participated in the U.S. Nuclear Infrastructure Council Advanced Reactor Technical Summit V and Technology Trailblazers Showcase, February 20-22, 2018, at the Texas A&M University, which provided opportunity to engage the advanced reactor developers in industry.
- **[ANL, INL]** The FCO campaign has been considering approaches for supporting the completion of a technology and systems readiness assessment for the versatile test reactor. The focus will be on the efficacy of the supply chain for building the reactor, as it is likely that most of the needed technology is currently available.

EQUILIBRIUM SYSTEM PERFORMANCE (ESP)

Performance of Fuel Cycle Systems

- **[ANL, INL]** Attended the U.S. Nuclear Infrastructure Council Advanced Reactor Technical Summit V and Technology Trailblazers Showcase, which was held at Texas A&M University, February 20-22, 2018. The reactor concepts and associated fuel cycles introduced in the summit have been reviewed in the FCO campaign except for “eVinci”, which is a micro reactor proposed by Westinghouse for decentralized generation markets such as Artic mines. The eVinci is a 0.3-15 MWe heat-pipe concept with monolithic core block, targeting commercialization in 2022. The information collection and review of the associated fuel cycle of the eVinci has been assigned to INL.
- **[ORNL]** Work is underway to review and update the reactor and fuel cycle concepts assigned to ORNL in the forthcoming ANL milestone.
- **[BNL]** Review of fuel cycle fact sheets developed by BNL in FY16 and FY17 is underway. Have started looking at information on “Fuel cycle(s) of Russia”.
- **[INL]** As a part of assignment for reviewing Nuclear Energy Systems (NES) and fuel-cycle concepts, documented the analysis report for U-Battery®. Started the review of reactor design and fuel-cycle characteristics for the Westinghouse’s eVinciTM micro reactor.
- **[INL]** Collaborating with a VISION code developer, worked on generating the nuclide recipes that could possibly be utilized for NEA/EGAFCS – TRU management study. Following benchmark specifications, both UOX and MOX fueled PWR assemblies were modeled using SCALE 6.1. Currently working for modeling of a break-even SFR core with recycled TRU fuel.
- **[BNL/PSU]** Draft equilibrium system performance summaries were generated for several concepts, including:
  - VVER-Based Floating Reactor Concepts (VBER -150/VBER-300)
  - Advanced Customer-friendly Practicable Reliable (ACPR50S) Small Modular Reactor
  - Marine Based Organically Cooled Nuclear Reactor for Enhanced Economics and Safety
  - Flexblue® Marine Based Transportable Small Modular Reactor
  - The draft summaries are presently undergoing internal review.

Economic Analysis Capabilities and Assessments

- **[INL]** Completed milestone M3NT-18IN120102031 "External Release of the FY 2017 Advanced Fuel Cycle Cost Basis report" in work package NT-18IN12010203, "Equilibrium System Performance - INL" on schedule. This involved having the 940 page report and 80 page supporting documents reviewed for external release, reviewed line by line for formatting, reviewed for completeness and consistency of references and being placed on an external website prepared for that purpose.
- **[ANL]** Completed the development of the bottom-up code for calculating the cost of containments featuring parallelepiped shapes, and wrote the corresponding section of the June report. The model can also be used for buildings housing reprocessing and fuel fabrication facilities, under the assumption that the construction standard for those facilities should be based on a level of physical protection similar to that of reactor containment buildings. This effort allowed the beginning of the development of a cost algorithm for fuel cycle facilities other than reactors.
- **[ANL]** The full list of the direct costs of the major components of the reference nuclear plant was revised. Two of the cost centers that contained several systems (e.g. the "Reactor Plant Equipment" cost account) were broken down into the individual sub-accounts, in order to allow an increase in the precision of the algorithm.
- **[ANL]** Visited North American Forgemasters (NAF), on February 23, 2018, in New Castle, Pennsylvania to obtain technical information to develop cost models for large mechanical components of nuclear plants, particularly forged ones. During the visit, some very important and unexpected points were learned. For example, instead of one cost model for the vessel, at least two will be needed: if the vessel is less than 6" thick, it will be plate-built and not forged, and the cost will be lower (this applies generally to the atmospheric reactor concepts, such as Na-cooled and molten salt). This, and other information learned during the visit, will help to develop a more credible and defensible model for the most important Nuclear Steam Supply System (NSSS) components. Cost data for plate-constructed structures was obtained from a combination of (a) the information gathered during the visit to NAF and (b) cost data from the Energy Economic Data Base (EEDB) for plate construction applied to the containment liner.
- **[INL, ANL]** Information about a cost breakdown, developed for the NASAP program in 1978 for standard UO2 LEU fabrication facilities, have been incorporated in the cost algorithm report for non-reactor fuel cycle facilities. It is possible that the cost of other fuel fabrication facilities could be estimated in first approximation by differentials with the cost of each fabrication step for standard UOX.
- **[INL]** Developing an approach for identifying the dynamic grid value of nuclear electricity by using RAVEN to run thousands of synthesized annual electricity demand and variable renewable energy (VRE) supply profiles on five minute time steps through an optimizer that manages net supply/demand imbalances with dispatchable electricity generation technologies.

Equilibrium System Performance (ESP) Tools Development

- **[ANL]** The implementation of the changes to the NE-COST website, which were identified through an ANL internal meeting and through follow-ups, is complete. External ANL accounts were created for the review by the FCO campaign personnel. After updating the external review comments from FCO campaign personnel, the NE-COST website will be open to the public.
- **[ANL]** Development of the EDGAR tool (Economic Dispatch Genetic AlgoRithms) was initiated this month to make it compatible with the type of energy market analysis considered within the Fuel Cycle Options Campaign. The EDGAR code optimizes the power output of the 65 plants on the APS

(Arizona Public Service) grid over a whole year to meet demand and reserve constraints while minimizing the cost of electricity generation. The code was translated from Matlab to Python, which allows slightly higher performance and portability to other operating systems. Some tests were implemented for checking the results of the economic dispatch and of the unit commitment procedures and compare them with the reference solution.

- **[SNL]** Identified specific areas of the catalog for improvement, such as finding a more efficient way to enter fuel cycle options into the database and updating the requirements document so it is consistent with the current structure of the catalog.
- **[BNL/PSU, ORNL]** Work has continued on the development of the transmutation database, (TDB) with the students and PSU. A schema for the TDB was created in MySQL. The students at PSU then populated two templates to test the templates effectiveness on storing the desired information for the transmutation database. ORNL was able to use these templates to validate the python code written to populate the TDB with the data. By running through the workflow for populating the TDB we were able to make a few corrections to the database import form and are much closer to having a final import form and are almost ready to start populating the TDB.

Development, Deployment And Implementation Issues (DDII)

Technology and System Readiness Assessment (TSRA)

- **[INL, BNL, ANL, LLNL]** Work on the Rev1 update to the TSRA report, "Technology and System Readiness Assessment Process for R&D Evaluation, FCRD-FCO-2016-000110, June 30, 2016, is nearing completion.
- **[INL, BNL, ANL, LLNL]** Regularly scheduled telecons have continued to discuss and plan the TSRA activities for FY18, including finalizing updated questionnaire for Technology and Systems Readiness Levels and updating the June 2016 report to reflect the "lessons learned". The plan is to apply the TSRA process to the evaluation of EG24 (continuous recycle of transuranics in a fast spectrum) from the Evaluation and Screening Study.
- **[ANL]** Participated in conference call and discussion on the TSRA for a fast reactor recycling option and continued the identification of critical technology elements of sodium-cooled fast reactor technologies. Reviewed the Lessons Learned report and provided the comments for revision of the report.
- **[LLNL]** provided additional review input for draft "Technology and System Readiness Assessment" process text and questionnaire in preparation for initial application to a complete advanced nuclear energy system.
- **[INL]** Completed refinement of system readiness level (SRL) questions to provide flexibility and completeness similar to the TRL questions. Refined the draft functional decomposition of the EG24 cycle. Started working with technical experts who will be applying the TSRA process to the separations system within the EG24 cycle. Initiated definition of assumptions, functions, and performance targets for transportation and uranium production systems within EG24 cycle.

Transition Analysis Studies

- **[ORNL]** The level 3 milestone "Report Identifying the Value Added by Fuel Cycle Dynamics Tools Directly Using Cross Section Data" has been completed on time and issued to Campaign management. All comments received from the reviewers were addressed in the final report.
- **[INL]** Attended the 16th meeting of the OECD/NEA Working Party on Scientific Issues of the Fuel Cycle on February 7, 2018. Status of Expert Groups and new NEA projects (especially Technology

Innovation 2050) were discussed. Chaired the 16th meeting of the OECD/NEA Expert Group on Advanced Fuel Cycle Scenarios on February 8-9, 2018 where the studies on bare SNF assembly dose rate modeling and TRU management scenarios were discussed. Both meetings were held at NEA headquarters in Paris, France.

- **[ORNL]** MSR core neutronic information has been generated and sent to ANL in order to compare the fundamental physics information with that of an SFR. This is to underpin the inter-comparison of MSR versus SFRs for breeding ratio potential. It is vital that the results are a best-estimate and like-for-like comparison of the two concepts, rather than being non-representative, otherwise the comparison being documented could be misrepresented when referenced in the future.
- **[ANL]** For comparison to the transition to EG24 with fast spectrum molten salt reactor (MSR), scenarios of transition to EG24 with SFR were simulated with theoretical recycling times of 7, 2, and 0 years. Extracted one-group cross sections and nu values from MSR and SFR models to perform simple physics comparison of breeding potential.
- **[INL]** Updated the economic cost model for evaluation of transition pathways for EG23 and EG30.

Regional and Global Analysis

- **[PNNL]** Preparing GCAM model and collecting data to assess regional impact of US renewable portfolio standards (RPS) on nuclear energy deployment. Currently 29 states have RPS policies in place. Eight of these states have RPS goals of 30% or higher by 2020 – 2030 timeframe. GCAM scenarios will explore the near and long-term impact of RPS on nuclear deployment at the state level and nationally.

Development, Deployment, and Implementation Issues (DDII) Tools Development

- **[ANL]** Hosted developers of the CYCLUS and CLASS tools, B. Mouginot (UW), X. Doliguez (CNRS), and N. Thiolliere (Subatech) to learn more about their capabilities as well as planning activities related to the 3rd Workshop on Dynamic Nuclear Fuel Cycle Analysis in Paris, July 2018.
- **[INL, ANL, ORNL]** Six abstracts have been developed for the “3rd Fuel Cycle Workshop”, to be held in Paris, France, 9-11 July, 2018. The abstract ideas were discussed amongst the campaign management and lab leads prior to the abstracts being produced. They include:
  - “The Fuel Cycle Analysis Toolbox”
  - “Impact of Technology Characteristics on Transition to a Fast Reactor Fleet”
  - “Economic Considerations in Fuel Cycle Transition”
  - “Molten Salt Reactor Modeling and Simulation Considerations”
  - “Modeling MSRs in DYMOND”
  - “Modeling a Fast Molten Salt Reactor with ORION”.
- **[INL]** VISION upgrades and testing continue, including the development of a 300-year, 4-reactor test case, which shows the flexibility of the code in ways that were previously anticipated, but not proven.
- **[ANL]** Listed the tools that have been used in the FCO campaign for fuel cycle analysis and the descriptions of each tool are under writing.
- **[ORNL]** Text is being drafted for the ORNL designated tools in the tools milestone report.

For more information on Fuel Cycle Options contact Temitope Taiwo (630) 252-1387.

Joint Fuel Cycle Study Activities

- The first fuel alloy from recycled U/TRU material (U-TRU-Zr-Ln) was cast in HFEF.
- Two DOE Level 2 Milestones, "Prepare JFCS Phase III CRADA" and "Prepare Nuclear Technology Transfer Sheets for JFCS Steering Committee Review" were completed on time.
- Process experiments for the fourth U/TRU recovery into liquid cadmium were completed. The recovered U/TRU button weighed approximately 100 grams. This test was performed using a traditional approach of driven-deposition into a liquid cadmium cathode.
- Analytical results were received for approximately 25 samples including OR Salt, ER Salt, and U/TRU material.

For more information on Joint Fuel Cycle Studies Activities contact Mike Goff (208) 526-1999 or 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, Massachusetts Institute of Technology, University of Utah, Rensselaer Polytechnic Institute, Washington State University, Colorado School of Mines, University of Nevada at Las Vegas, Clemson University, University of South Carolina, Purdue 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
Idaho State 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
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

- University Research Alliance continued to send out the program announcement for the 2018 Innovations in Nuclear Technology R&D Awards competition and accept and process applications from students. The program was announced on January 29.
- University Research Alliance conducts a significant outreach effort to acquire the applications. The announcement is sent to more than 24,000 faculty in relevant disciplines at universities throughout the United States. The announcement is also sent to a number of web sites including the American Nuclear Society, the Nuclear Energy Institute, and science.gov. It is also sent to ANS student chapter presidents, INMM student chapter presidents, and university research centers that conduct nuclear technology research. Students and their advisors who have won awards in previous years are informed of the opportunity so that they may apply again, if eligible, and pass the information on to their colleagues. Announcements are sent to nuclear engineering department heads and faculty who are known to be conducting nuclear technology research.

- The outreach objective is to ensure that every student who may be eligible for an award is informed of the opportunity. The number of applications has increased slowly over the life of the program, but the pool of potential applicants is a small one. The number of applicants is significantly affected by the amount of research any one faculty member may be conducting, and the research stage. It seems clear that university research support and this type of university program are essential to educating students with expertise specific to nuclear technology.
- The vast majority of applications are usually received in the final week, with many of those being received in the two days before the deadline. The scheduled deadline for 2018 is midnight Sunday March 18.
- To apply, a student submits an application and a recently published paper on which the applicant is the first author or the primary student author. There are three competitions:

Open Competition

- Publications from eligible students at all universities are eligible for this competition. Awards are $3,000 for First Place and $2,500 for Second Place in each of the following categories:
  - Advanced Fuels (including in-core materials and cladding, materials science, in-core instruments, detectors, sensors and nano-scale structures and materials)
  - Advanced Reactor Systems (including material science, advanced alloy development and testing, nuclear physics, nuclear reactor thermal hydraulics, fast reactor concept development, advanced reactor design)
  - Energy Policy (including decision support simulators which may include game theory, economic modeling, and applied mathematics)
  - Material Protection, Control, and Accountancy (including instrumentation, detectors, and sensors for safeguards and nonproliferation applications)
  - Material Recovery and Waste Form Development (including advanced extraction technology for dry and wet recycling of used nuclear fuel, advanced waste form development and its characterization, uranium resources, thermodynamics and kinetics)
  - Nuclear Science and Engineering (including nuclear physics, nuclear chemistry, radiochemistry applicable to R&D nuclear fuel cycle, generic geology repository)
  - Used Fuel Disposition (including storage, transportation, disposal of commercial used fuel, behavior of actinides and radionuclides under generic repository conditions)

Competition for Students Who Attend Universities with Less Than $600 Million in 2016 Science and Engineering R&D Expenditures

- Publications from students at universities which have lower research outlays are eligible for this competition. Awards are $1,500 each for five students.

Undergraduate Competition

- Publications from undergraduate students at all universities are eligible for this competition. Awards are $1,000 each for up to five students.
- University Research Alliance has been removing email addresses for rejected announcement emails and removing addresses of people who have asked to be unsubscribed from the list. This process will continue with each announcement.

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