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Metrics Development for ATF

- **[INL]** A presentation was delivered at the EPRI/DOE/INL ATF Workshop at the EPRI Fuel Reliability Program Meeting, held February 22-23. This presentation provided an overview of the metrics established for ATF technical evaluation, a definition of "coping time" and an explanation as to how that coping time definition was determined within the international community at the NEA Expert Group on ATF for LWRs. Due to travel conflicts, the presentation was given by Jon Carmack. Brad Merrill also prepared and delivered a presentation at this meeting to provide an overview of the MELCOR analysis of ATF behavior that has been performed by INL. This presentation included discussion of MELCOR modifications for severe accident analysis, application of the modified MELCOR to the Three Mile Island accident, and application of the modified MELCOR to a large-break loss-of-coolant accident. (S. Bragg-Sitton)
- **[INL]** INL organized and participated in a meeting of the ATF Industry Advisory Committee on Friday, February 24. This committee provides useful input from the utility and vendor perspective on ATF development, testing, and ultimate insertion in a commercial reactor. All 3 vendors are currently working toward a 2019 insertion of a lead fuel rod in a commercial reactor, versus the previous 2022 goal. Discussion focused on what data would be available to support early insertion and what data would be needed; no TREAT data is expected to be necessary to gain approval of a lead rod insertion. Jon Carmack participated in the IAC meeting in person; Shannon Bragg-Sitton participated via call-in. (S. Bragg-Sitton)

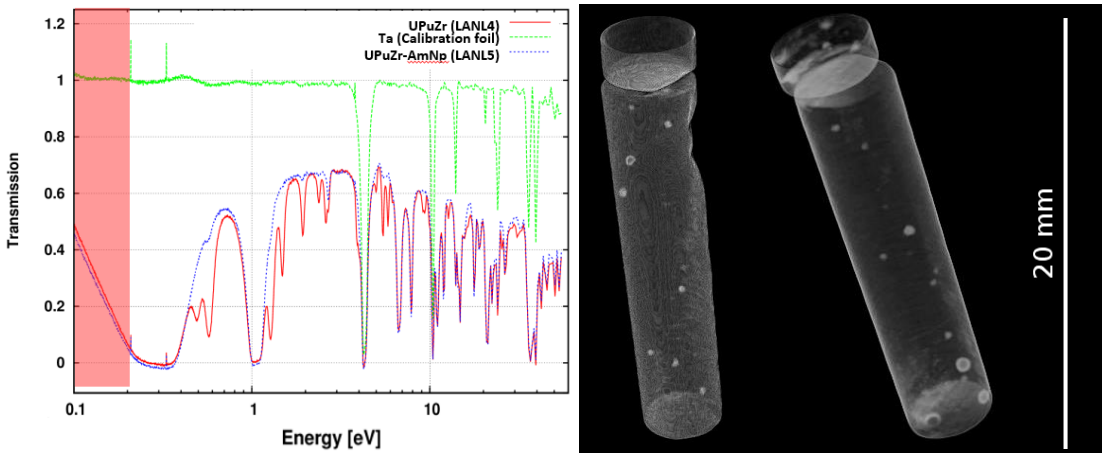
Analyses

- **[BNL]** Three-dimensional PARCS core models at hot zero power (HZP) fuel and moderator conditions have been created at Beginning-of-Life (BOL) for UO_2/Zircaloy fuel (reference) and UO_2/FeCrAl and U_3Si_2/Zircaloy ATF fuel/cladding concepts. The cores contain three enrichment zones and integral fuel burnable absorbers (IFBAs) based on data in the AP-1000 Safety Analysis Report. Testing of the models has been completed, and the generated point kinetics parameters are being implemented in the TRACE systems code. The PARCS models have been utilized to calculate the reactivity vs time for the shutdown banks. (A. Cuadra, M. Todosow)
- **[BNL]** The TRACE PWR plant model has been modified to initialize the model for hot zero power (HZP) conditions. Steps have been taken to expedite the convergence of the primary system to the HZP conditions: 1) eliminate extraneous heat sinks, such as pipe walls and 2) use of constant temperature boundary condition for the heat structure representing the u-tubes in the steam generators. The power component in the model has been updated with the point kinetics parameters and control rod reactivities described above. The TRACE model will be used to analyze reactivity initiated accident (RIA) at HZP for different ATF fuel designs. (L.-Y. Cheng, A. Cuadra)

LWR Fuels

- **[LANL]** A manuscript titled, "The Effect of Aluminum Additions on the Oxidation Resistance of U_3Si_2," was accepted for publication in the *Journal of Nuclear Materials*. Although U_3Si_2 possesses both a high uranium density and improved thermal conductivity compared to reference UO_2 fuel, recent research at LANL has established that the fuel suffers a key vulnerability to oxidation. Pulverization of U_3Si_2 pellets rapidly occurs during exposures to oxygen or pressurized water at temperatures above 300C. The authors (E. Sooby Wood, J.T. White, and A.T. Nelson) of the new study report results of dilute Al additions on the oxidation behavior of U_3Si_2. Four U-Si-Al compositions were synthesized using arc melting. These compositions were then oxidized under a range of conditions and compared to U_3Si_2. The investigation found that increasing amounts of Al delayed the onset of breakaway oxidation for U_3Si_2. An aluminum-containing oxide layer, assumed to be Al_2O_3, formed on the surface of an $U_3Al_2Si_3$ sample exposed to 500C air. Further, this sample did not pulverize after hours of exposure whereas a monolithic U_3Si_2 pellet would be reduced to powder after only minutes under a comparable condition. This result will be explored further in coming months as a means to facilitate use of U_3Si_2 in LWR environments (E. Wood).
- **[LANL** Hydrogen may be present in LWR environments either when intentionally introduced into PWR coolant or resulting from steam oxidation of cladding or structural materials during off-normal conditions. The response of fuel and cladding materials to hydrogen-containing environments is therefore an essential component of qualification for LWR service. The first results were obtained to investigate the response of U_3Si_2 to hydrogen-containing environments. U_3Si_2 powder and pellets were exposed to Ar-6%H_2 at 355C for 12, 20, and 50 hour exposures. X-Ray diffraction data collected following these exposures show clear incorporation of hydrogen into the structure. The terminal hydride phase appears to be $U_3Si_2H_{1.8}$. Physical effects of the incorporation of hydrogen are extreme, as pellets tested lose all integrity and pulverize. Testing is ongoing to better understand the kinetics and temperature regimes of relevance to this process. (E. Wood)
- **[LANL]** A number of high density ceramic nuclear fuels for LWR deployment are being considered both within AFC as well as around the world. Uranium mononitride (UN) is a key component of many of these concepts given its high uranium density and favorable properties, both in the unirradiated state and under irradiation. A key vulnerability of UN is its susceptibility to oxidation. UN must therefore be incorporated into an LWR fuel as a composite such that it is shielded from degradation in the event of any cladding failure. The vast majority of irradiation experience for UN has been obtained under fast reactor conditions. Little experimental data is available regarding its behavior under irradiation conditions representative of those anticipated for LWR service. A test irradiation of UN has been proposed and accepted for the Halden Joint Program ATF Fuel Test (IFA-808). The test will specifically focus on the thermal conductivity, swelling, and fission gas retention of UN fabricated at LANL where carbon and oxygen impurities are controlled. Discussions with Halden design engineers regarding the proposed irradiation has commenced. A dialogue was established such that key fabrication parameters (e.g. U-235 enrichment, pellet dimensions, supporting documentation needs) can be determined in advance of fuel fabrication (A. Nelson).
- **[LANL]** A report, "SET Stakeholder crystal growth prioritization" was completed, M4FT-17LA0202020212. The report briefly describes and prioritizes the key materials of interest to separate effects testing stakeholders in the Advanced Fuels Campaign and NEAMS for near term work. The two main materials of interest are U_3Si_2 and UO_2 due to continued data needs. Based upon these needs, upcoming crystal growths will focus on these materials to bridge gaps in the data sets for physical and thermo-physical properties. (D. Byler)
- **[LANL]** Neutron tomographic reconstructions using a discrete energy range of 0.1 to 0.2 eV have been completed on two capsules containing U Pu(20wt%) Zr(10 wt%) slugs (provided by R. Fielding, INL). Each slug was double encapsulated and sealed with sodium. The slugs (each approximately

19mm long) in one capsule also contain Americium and Neptunium at 2 and 3 wt% respectively. The 0.1 to 0.2 eV energy range corresponds to a region where the absorption is dominated by 240Pu (nominally 2.7 wt%) but where the transmission is not saturated (see Figure 1a) below). The difference between the red and the blue transmission spectra in Figure 1a) are due to distinct Am and Np resonance cross sections. A 3D reconstruction for each sample is shown in Figure 1b and c below. Both samples show approximately 10 regions where the sample is substantially depleted in (at least) 240Pu. The features are nominally spherical with diameters ranging from approximately 0.5mm to the experimental resolution of 0.08mm. Also visible near the top of Figure 1b is a casting irregularity (apparent as a deviation from cylindrical geometry). Analyses using the SAMMY program to fit the resonance data are ongoing and will produce isotope-specific 3D reconstructions for the constituents (that have useable resonances in the 0.1 to 50eV range). This analysis will assess whether there are regions of isotopic enrichment or depletion and contribute to assessment of whether the features shown in Figure 1b) and c) below are voids or result from compositional variation. (A. Losko, S. Vogel)



a) b) c)

Figure 1. a) Neutron transmission spectra for UPuZr (LANL4), UPuZr AmNp (LANL5) and Tantalum foil (used for calibration) b) Tomographic reconstructions of features in b) UPuZr (LANL 4) and in c) UPuZr-AmNp (LANL5). The field of view in each case was 28mm which included one slug and the tip of an adjacent one visible in b) and c)

LWR Core Materials

Thin Walled Tube Development

- **[INL]** The Coherent laser power meter was fixed, re-calibrated and has now been received back at INL. LBW studies will be re-initiated in March. (J. Gan)
- **[INL]** Samples 35-3, 35-4 & 35-5 were handed off for CT analysis to be conducted prior to initiating follow-up testing. Results are expected in early March. (J. Gan)
- **[INL]** Sample set 36 samples CT analysis was completed in February (Figure 2). Sample set 36 consists of PRW joined samples and were subjected to a PWHT. The joining parameters used for sample set 36 samples were the sample joining parameters used for samples sets 34 & 35. Samples 36-1 – 36-4 will be used for hydraulic pressure rupture testing; which will be conducted in March. CT analysis showed most of the samples formed a good bond during the joining process. One exception

being sample 36-2, the bond doesn't show the same level of deformation as the other rupture samples – the sample may be withheld from further testing. (J. Gan)

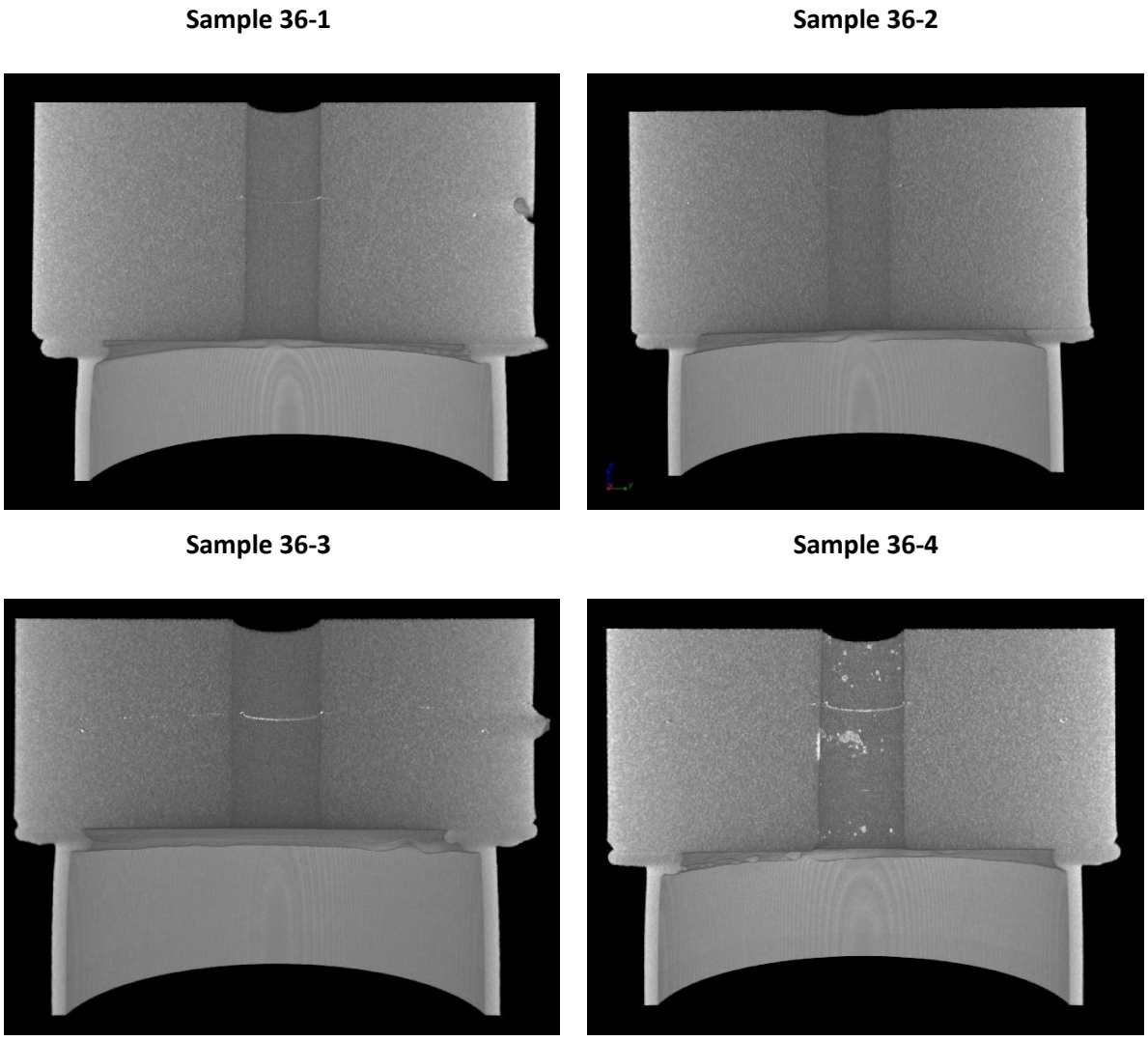


Figure 2. Sample set 36.

- Samples 35-1 & 35-2 were bonded with the PRW system and were then subject to tensile testing in the 'as-welded' condition, i.e. samples were not subjected to a post-weld heat treatment process. These samples were joined using the sample joining parameters used for sample set 34; samples 34-2 & 34-4, which were subjected to a PWHT, showed positive tensile results.
- Tensile data of samples 35-1 & 35-2 is plotted along with samples 34-2 & 34-3 for comparison – load vs. displacement (Figure 3) and stress vs. strain (Figure 4).

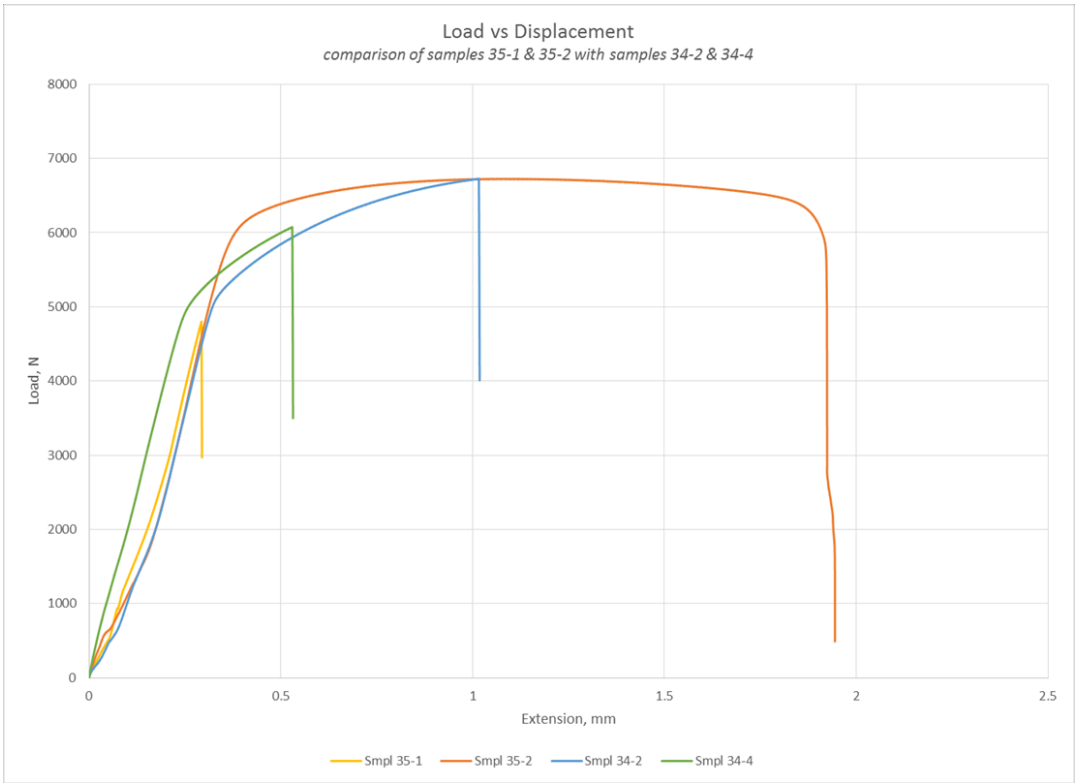


Figure 3. Load vs. displacement - comparison of samples 35-1 and 35-2 with samples 34-2 and 34-4.

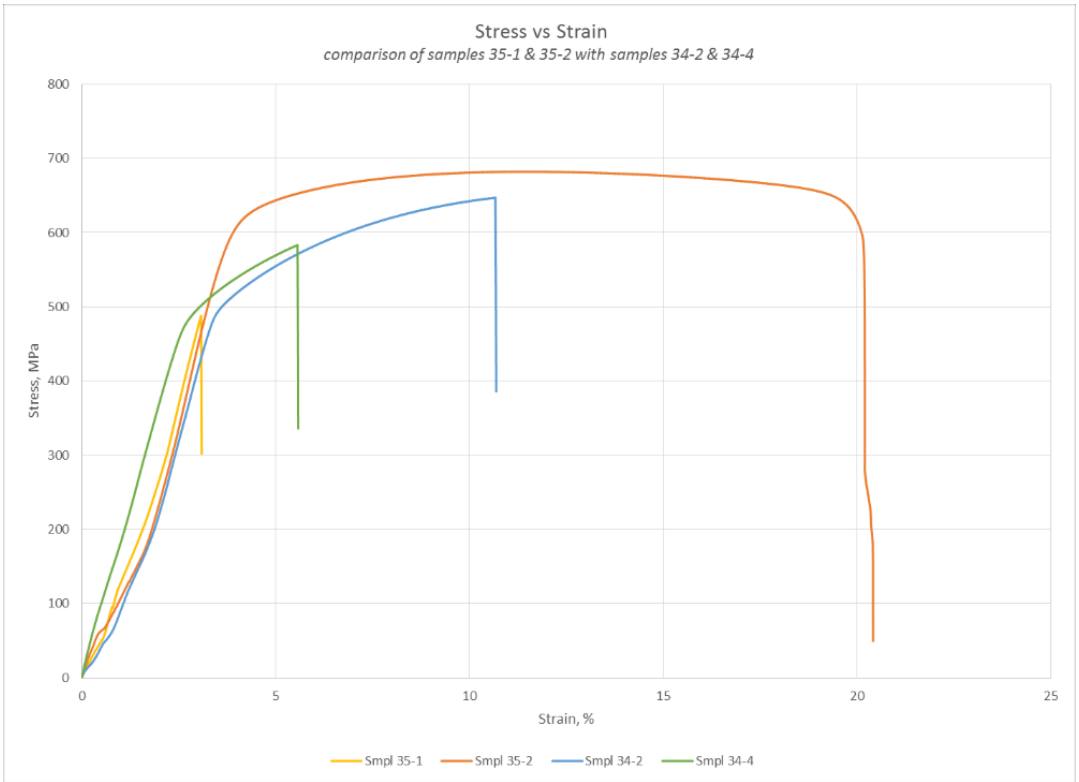


Figure 4. Stress vs. strain - comparison of samples 35-1 and 35-2 with samples 34-2 and 34-4.

- **[INL]** Sample 35-2 showed positive results exhibiting deformation within the tube followed by complete failure in the tube through its tension test. Sample 35-1 showed the bond peeled apart on one side of the bond and then under continued pulling showed tearing within the tube on the opposite side of the bond (Figure 5). The result of 35-2 indicates a PWHT may not be necessary for bonds generated via the PRW process (Figure 6). Further investigation is required to confirm it. Given the favorable test results of sample 35-2, additional samples were bonded using the PRW process, samples 35-3 – 35-5, to conduct additional tensile testing in the 'as-welded' condition. (J. Gan)

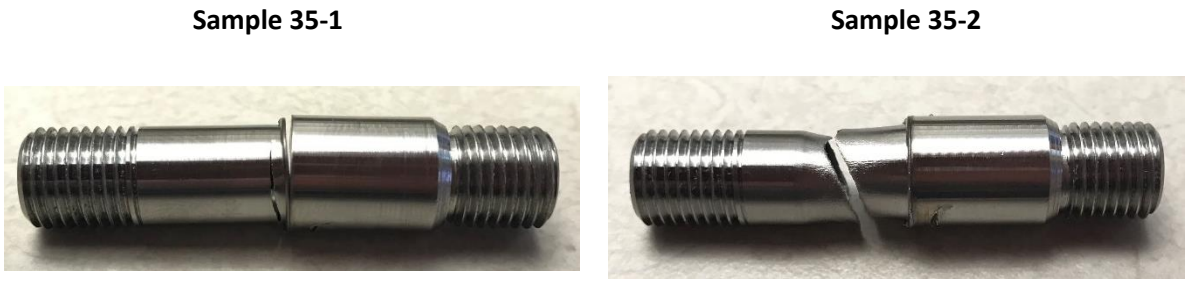


Figure 5. Sample 35-1, 35-2.

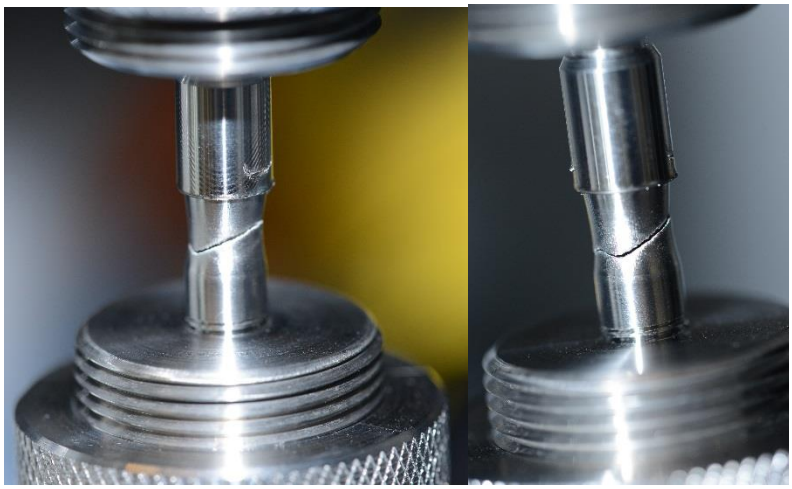


Figure 6. Additional pictures of sample 35-2.

Advanced LWR Materials Development and Testing

- **[ORNL]** Procurement of thin-wall Gen II. C26M alloy tubes (Fe-12Cr-6Al-2Mo-Si-Y, wt.%) is in progress. Centerless grinding of 9 master bars was completed and the bars were delivered to Century Tubes, Inc. on Feb. 28th. Century Tubes agreed to fabricate the thin-wall seamless tubes with the target completion date of June 23rd, 2017. An additional 9 extruded bars were straightened and annealed at ORNL, and then shipped to the machine shop for centerless grinding. These machined bars will be delivered at ORNL mid-March, 2017, and then shipped to Century Tubes for additional tube productions. The tube production will be distributed to the collaborative partners for property evaluation. The second heat of VIM+HIP C26M ingots will be prepared at Sophisticated Alloys, Inc. for further additional tube production. (Y. Yamamoto)
- **[ORNL]** An adiabatic hot-forging process of two Nb-containing FeCrAl alloys (Fe-13Cr-6Al base with 0.7 and 1 Nb, wt.%) with ~75% total deformation in one pass was performed at 900-1100 °C, in order to evaluate the microstructure evolution during relatively rapid hot-deformation simulating hot-extrusion process of the alloys. Represented cross-sectional microstructures of the forged piece are

shown in Figure 7 . At 900 °C, both alloys showed only heavily deformed grains without recrystallization. On the other hand, a partially recrystallized grain structure was observed at 1100 °C with the grain size of 30-50 µm. For comparison, the grain size of the extruded C36M3 (Fe-13Cr-6Al-2Mo alloy) at 900 °C was ~50-80 µm. The results suggest that the refined grain structure with random texture formation can be expected in the Nb-containing FeCrAl master bars after extrusion and annealing process, based on the previous texture evaluation studies. Such random texture formation will be beneficial for the deformability of the master bars/tubes during the tube reduction process. Detailed microstructural characterization is currently in progress. (Z. Sun, Y. Yamamoto)

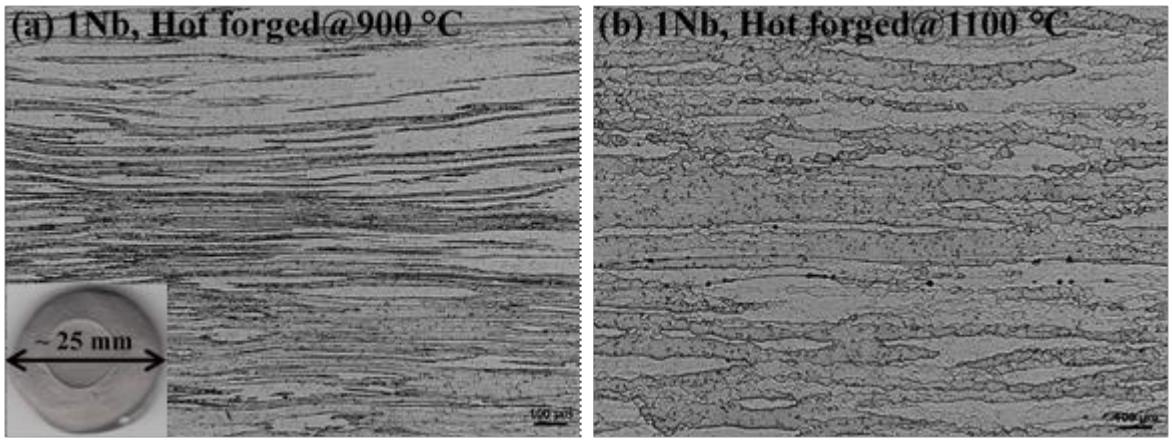


Figure 7. Cross-section micrographs of hot forged FeCrAl bullets with 1 wt%Nb at (a) 900°C and (b) 1100°C. A picture of the hot-forged piece is shown in the inset of (a).

- **[LANL]** Ion irradiations to doses up to 15 dpa at 300C using Fe ions were completed on two Gen II alloys in tube form (C06M2 and C36M3). Following irradiation, nanohardness was performed on samples and the results were compared with those measured on plate material of the same Gen II alloys. In addition, the microstructure was characterized using TEM. Results will compiled in a report to meet a L3 milestone. Hardening observed after irradiation saturated after 5 dpa and was very similar to measurements previously made on plate material. (S. Maloy)
- **[ORNL]** Three mm thick small plates were machined from the tail of the extruded bars used to produce the Fe-10Cr-6Al-0.3Zr + Y2O3 rods that were shipped to Japan for tube fabrication. 40% cold rolling with a 10% reduction per pass was conducted to simulate tube cold pilgering, a required step for the fabrication of thin tubes. Surprisingly, cold rolling led to a slight decrease of the alloy hardness, from ~302HV to 288HV. Subsequent annealing resulted in a further decrease of the hardness values, 281HV and 261HV after 1h at 1000ºC and 1100ºC, respectively. (S. Maloy)
- **[ORNL]** TEM microstructure characterization of two Fe-10Cr-6Al-0.3Zr alloys extruded at 900ºC and 1050ºC revealed the presence of fine (Y,Al)-rich oxides as well as larger Zr rich precipitates. As has been reported in the literature, lowering the extrusion temperature resulted in finer oxides and smaller grain size. (S.Dryepondt)
- **[ORNL]** Simplified 3D fuel pellet-cladding simulations were run with coarse mesh and modified boundary conditions to solve the issue of non-convergence. These simulations employed half geometry and mirror boundary conditions to reduce the computation time. (G.Singh, Y.Katoh)
- **[ORNL]** The mechanical properties data of SiC/SiC tubes, obtained from the interlaboratory round robin testing, is being analyzed in detail. The results from initial analysis were discussed with the participants to ensure consistency of the method for measurements, and reporting of any deviations from the standard method of testing. The DIC system, which will be employed for assessing the

accuracy of measured strains in the upcoming hoop tensile testing of SiC/SiC tubes, is being set up. (G.Singh, Y.Katoh)

- **[ORNL]** High-dose irradiation effects on SiC/SiC composites: STEM observation of Hi-Nicalon Type S fiber with and without neutron irradiation was conducted. Figure 8 shows STEM bright field (BF) and high angle annular dark field (HAADF) images of the fiber unirradiated and irradiated at 280-280°C to 11.8dpa. The black and white contrasts in the BF images indicate SiC grain and carbon phase, respectively, and the contrast is vice versa in the HAADF image. Image analysis showed there is no significant change in size and distribution of the SiC grain and carbon phase. This microstructural stability is consistent with strength retention of the irradiated composite confirmed by a flexural test. The PIE of 11.8dpa irradiated SiC/SiC composites has been completed. A draft of level 2 milestone report on this PIE task was prepared. (T.Koyanagi, Y.Katoh)

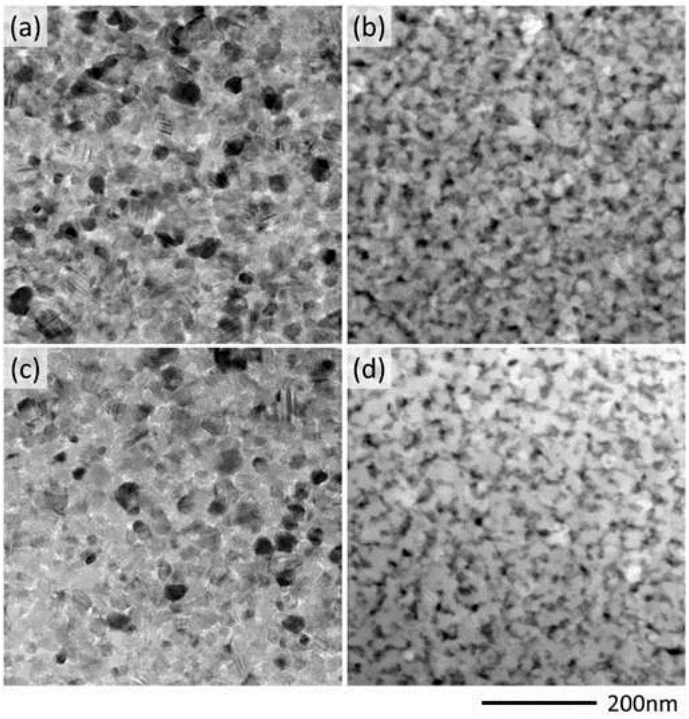


Figure 8. STEM micrograph of Hi-Nicalon Type S fiber: BF (a) and HAADF (b) images of the unirradiated fiber, and BF (c) and HAADF (d) images of the fiber irradiated at 280-280 C to 11.8 dpa.

- **[ORNL]** Seven coatings and four bond coats based on electrochemical, vacuum plasma spray and physical vapor deposition were developed in 2015-2016. The most feasible variants of these coatings were neutron irradiation without coolant to determine irradiation response. The shipping of the samples post-irradiation is being arranged and are scheduled to arrive by mid-May. A more advanced set of coatings was developed and irradiated in-pile in the presence of coolant. The physical vapor deposition coatings appear to be more promising than the others. Both vacuum plasma spray Zircaloy-2 (VPS Zr) and electrochemical coatings continue limited development. The optimization of the coating by mass fraction and texture of Zr in the VPS coating is a priority. Recently, the parameters necessary to retain >95% Zr were found. In the electrochemical coatings, the successful deposition of Cr on either PyC or Ni suggested that microcracks in Cr appeared to expand after irradiation. This indicates that electrochemical coatings may not be feasible and research on these coatings is directed toward publication and will be presented at PACRIM9. (C.Ang, Y.Katoh)

- **[ORNL]** Steam testing of 1st generation FeCrAl tubing (B136Y) continued in various ramping cycles to support accident modeling of this new alloy. Characterization of reaction products is in progress with peak temperatures of 1400°-1550°C. Steam oxidation kinetics comparison with commercial alloy APMT is being developed. (B. Pint)

LWR Irradiation Testing & PIE Technique

- **[INL]** All technical and procedural documents associated with the shipment of three irradiated ATF-1 capsules in the GE-100 cask have been written and approved. The completion of these documents directly affects the ability for two ATF-1 milestones to be completed on schedule. (G. Core)
- **[INL]** Preparations were made to receive new ATF-1 rodlets from ATR which include 2 Westinghouse U3Si2-Zirlo concepts and one ORNL UO2-FeCrAl concept for LOCA testing. This shipment is expected early in the next reporting period. (J. Harp)
- **[INL]** Revised ATF-2 design drawings were completed in February. We are awaiting final reviews for release. (K. Barrett)
- **[INL]** The Sensor Qualification Test (SQT) drawings and safety analyses were completed with the exception of the structural analysis which is in process. (K. Barrett)
- **[INL]** ATR chemistry conditioning test for cycle 160B-1 was completed (cycle SCRAM occurred 2/23/17) with positive results. Monitoring will continue cycle 161A (14 day PALM) in preparation for the sensor qualification test (SQT) insertion the following cycle 162A-1. (K. Barrett)
- **[INL]** The data acquisition system at ATR (DCS) is being modified for operation control and monitoring of ATF-2 water loop sensors. The data will be downloaded onto the NDMAS database system for program access, analysis, and review. (K. Barrett)
- **[INL]** A Cooperative Research and Development Agreement (CRADA) between INL and Westinghouse was approved to support a collaborative effort to test a variety of sensors in a mock-up test to be performed in an autoclave loop at the Westinghouse Churchill, PA facility. The autoclave test is scheduled to begin in early April 2017. Results will support SQT irradiation testing in ATR cycle 162A-1. (K. Barrett)
- **[INL]** Test train components for the autoclave and SQ tests have been fabricated and a majority of the ATF-2 test train components (that are similar to the SQT) have also been fabricated. Fuel rod fabrication is in process. (K. Barrett)
- **[INL]** Instrument lead brazing development was completed. Procedures and qualifications are in process. Instrument lead assembly for the autoclave test are in process with anticipated completion by mid-March. (K. Barrett)
- **[INL]** Preparation for the SQT cycle 162A-1 is underway at ATR with plans to install all sensor cabling/wiring, gas panel, electrical panel, and control equipment/cabinet cycle 162A-1 outage. (K. Barrett)
- **[INL]** In support of the upcoming ATRC run, U3Si2 pellets have been fabricated at MFC and commercial pellets have been received from GNF to support fabrication of surrogate “backup” rods to be used in the ATRC test train. Six already fabricated fuel rods (under ATF-1B) by AREVA will be shipped to INL in May 2017 to be used as surrogate rods for the ATRC run as well. The ATRC run is planned to start sometime this summer (June-August). (K. Barrett)
- **[INL]** The ATR data packages for the SQT and ATF-2 tests have been submitted for ATR review and approval. (K. Barrett)

- **[INL]** The detailed designs for single and dual cluster BWR/PWR rigs were completed and audited internally by IFE. Safety assessment and initial data export licensing began in February. (E. Mai/K. Barrett)

LWR Transient Testing

- **[INL]** Finalization of rev 0 calculation reports for Multi-SERTTA are now complete. This completes the incorporation of design review comments into the design (with the exception of those comments that cannot be address until the completion of prototype testing). (J. Schulthess)
- **[INL]** Drawings for prototype fabrication were created and nearly all of the machining for prototype primary vessels is complete. (J. Schulthess)
- **[INL]** Nearly all prototype component procurements are placed. Brazing process qualification samples recently produced (enables instrument leads to penetrate into vessel) (J. Schulthess)
- **[INL]** CAL mechanical design prepared for design review, and engineering drawings are created. Neutronic, thermal, and structural models created and successfully run for –CAL design review. (J. Schulthess)
- **[INL]** The Test Plan revision is continuing on schedule. (D. Dempsey)
- **[ORNL]** Pre-installation, LOCA system calibration, alignment and benchmark testing at 1200C of Zr-4 specimens in the ORNL Severe Accident Test Station (SATS) was successfully completed. (Figure 9) Comparison between strapped and welded thermocouples showed ΔT of 3°C. Alignment of tube furnace showed 4 thermocouples (mid-plane, 2-in below at 0°, 2-in above at 0°, and mid-plan at 180°) with a ΔT of 10°C. Benchmark LOCA tests were conducted at 1200°C for 0, 600, 900 and 1200 psi (Figure 10). All samples ruptured within the middle 4" section. The system is prepared for in-cell installation planned for April 2017. (Y.Yan, K.Linton)

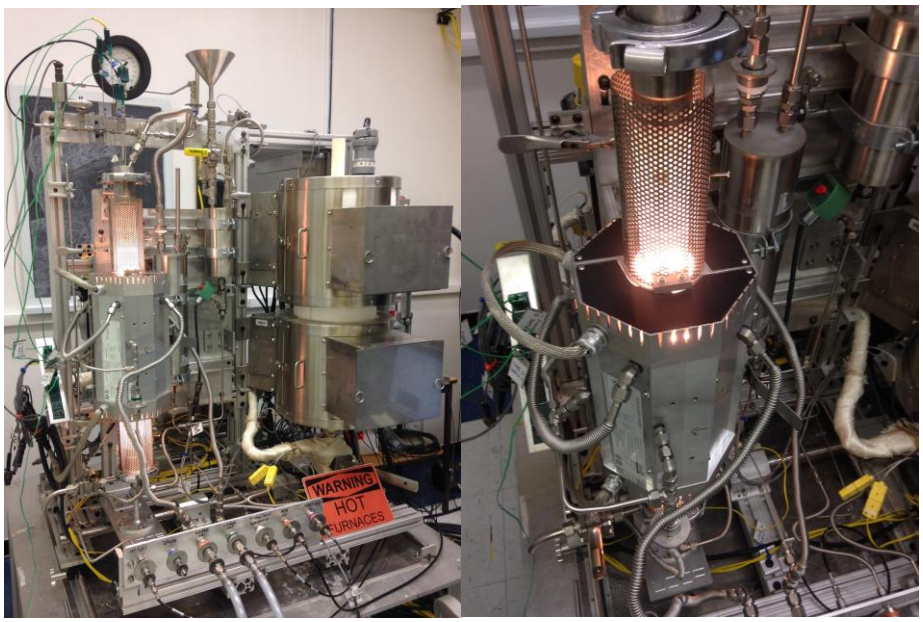


Figure 9. SATS during LOCA testing at 3525 (IFEL) prior to in-cell insertion in April 2017.

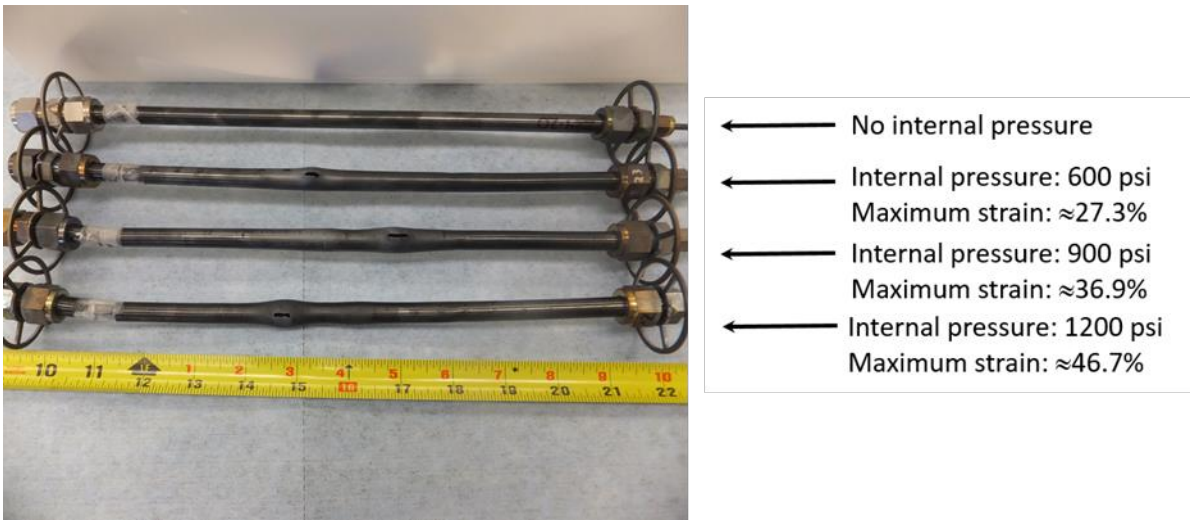


Figure 10. Four test rigs from benchmark LOCA tests at 1200 C for CP-ECR=17%.

- **[ORNL]** Dr. Nedim Cinbiz presented the pulse controlled modified burst test at the TMS International 2017 by showing mechanical test results of unirradiated hydrided ZIRLO™, Gen-I FeCrAl, and silicon carbide fiber/silicon carbide matrix composite (SiC-SiC). The talk highlighted the importance of dynamic testing and to appropriately simulate the pellet-clad mechanical interaction (PCMI) phase and the failure modes of distinct accident tolerant fuel cladding candidates (see Figure 11) during reactivity-initiated accident conditions. Figure 11depicts the PCMI failure of Zircaloy-4 after RIA integral tests (Nagase-Fuketa 2005) and the expected failure mode of current cladding (Fuketa 2012). In addition, Figure 11 depicts new AFC results for pulse controlled modified burst testing of hydrided ZIRLOTM, Gen-I FeCrAl, and SiC-SiC composite. The ZIRLOTM failure mode is similar to the integral tests of Zircaloy-4. On the other hand, Gen-I FeCrAl failure showed multiple branches of axial cracks, which is strongly affected by the cladding grain microstructure. Importantly, the SiC-SiC composite tests have shown no axial crack propagation because of the enhanced strength as a result of its fiber bundle architecture. (M. N. Cinbiz, N. R. Brown (PSU), K. A. Terrani, K. Linton)

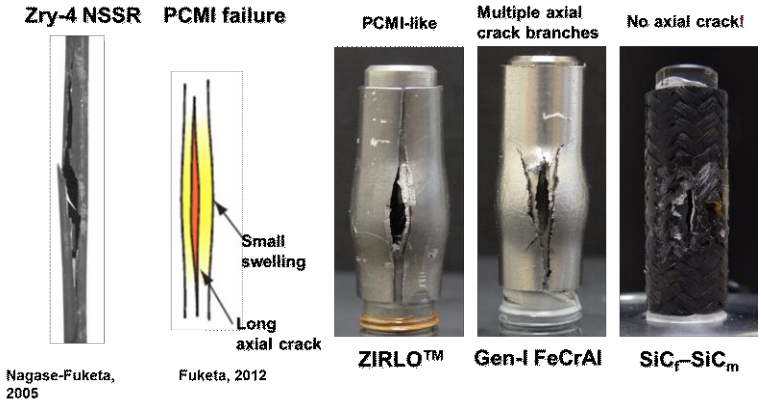


Figure 11. The PCMI failure mode comparison of different ATF cladding candidates with the expected failure mode of current cladding materials.

ADVANCED REACTOR FUELS

AR Computational Analysis

- **[INL]** Calculations of the columnar grain region diameter in AFC-2C experiment were performed and results are being compared with experimental measurements. (Figure 12) (P. Medvedev)

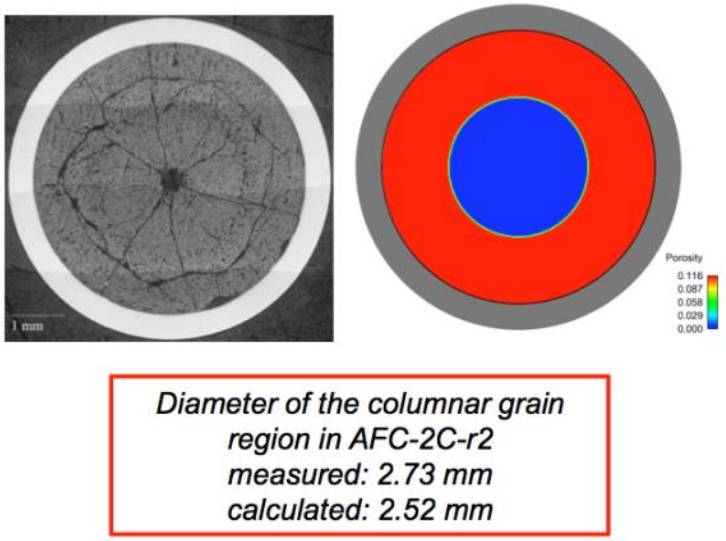


Figure 12. Diameter of the columnar grain region in AFC-2C-r2.

AR Fuels Development

- **[INL]** Work on the Transmutation Fuels Handbook focused on synthesis and evaluation of data on phases and phase transitions in U-Np-Pu-Am-Zr alloys (Figure 13). Much of this data was initially documented in INL reports, and some has not been published elsewhere. This data will be drafted into the next edition of the handbook. (C. Papesch)

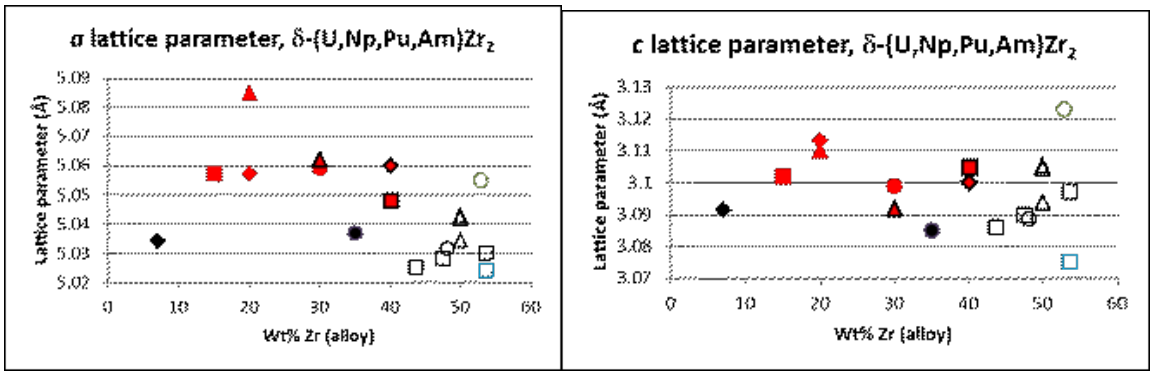
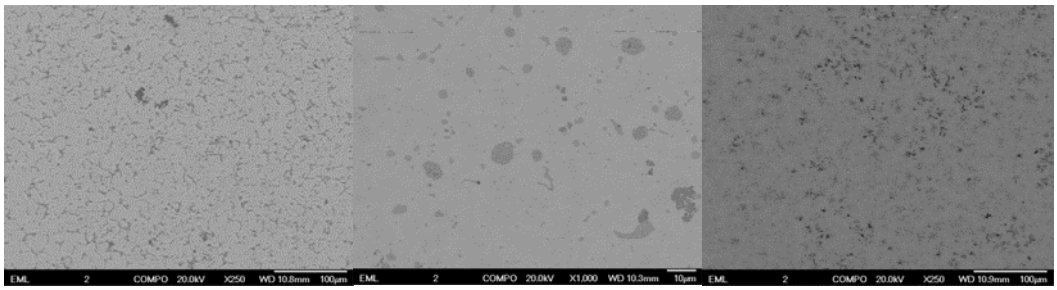


Figure 13. Phase and phase transition data for U-Np-Pu-Am-Zr alloys.

- **[INL]** Samples of U-20Pu-10Zr-3.86Pd, U-20Pu-10Zr-3.86Pd-4.3Ln (where Ln = 53Nd-25Ce-16Pr-6La), and U-19Pu-4.3Ti-0.7Zr-5Mo were analyzed by scanning electron microscope. Figure 14 shows representative backscatter images from each alloy. This data was recently received, and is being analyzed.(C. Papesch)



a) b) c)

Figure 14. SEM image for a) U-20Pu-10Zr-3.86Pd, b) U-20Pu-10Zr-3.86Pd-4.3Ln, and c) U-19-Pu-0.7Zr-4.3Ti-5Mo.

- DSC data on these alloys was conducted to compare as processed and annealed materials (Figure 15). (C. Papesch)

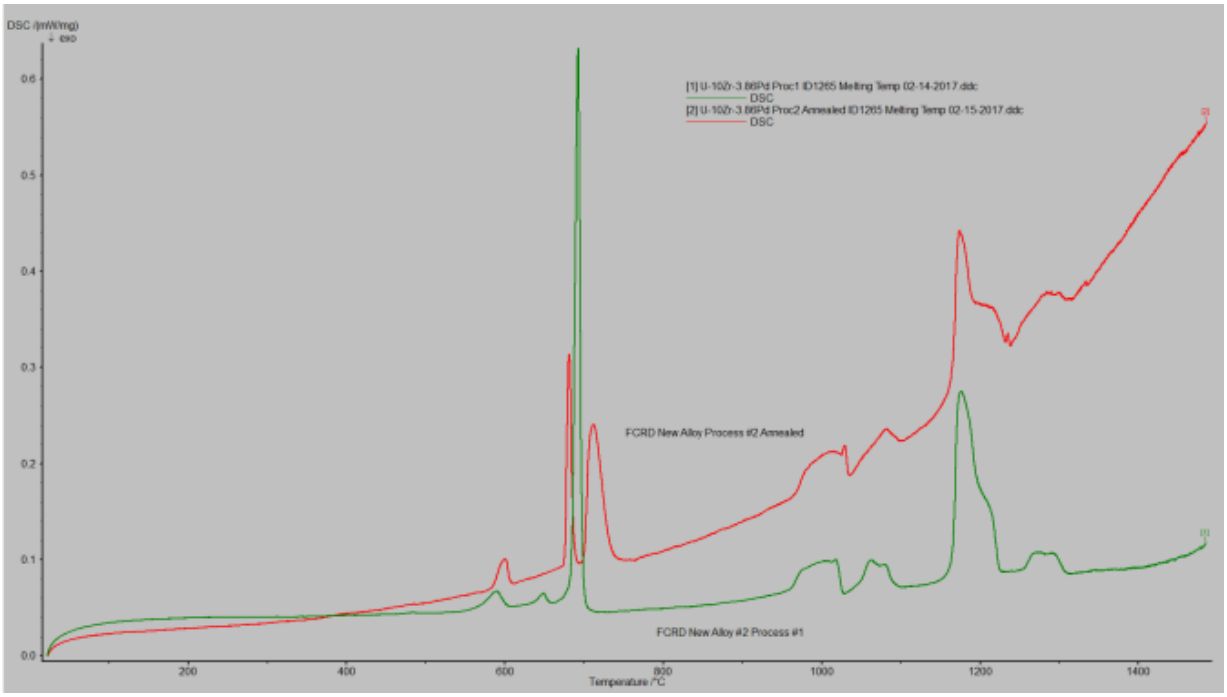


Figure 15. DSC data.

- **[INL]** The americium metal that was oxidizing in the inert atmosphere glovebox was all consolidated into larger spheres in order to reduce surface area and limit oxidation potential. In addition, the level three milestones to complete the first set of americium distillation runs was met. (L. Squires)
- **[INL]** Work under the Advanced Fabrication Package has continued in the areas of integral fuel cladding chemical interaction (FCCI) barrier fabrication, stoichiometry control and transmutation oxide fuel fabrication development, and improved small scale casting furnace design. As previously reported that thicker barrier foils are easier to work with as well as tend to contain the molten fuel better, however, thinner barrier materials will have fewer impacts of fuel composition and overall fissile content. Based on this a 0.002" foil was used for further development. A standard pin was cast

contained within a 0.002” thick zirconium foil (Figure 16). The pin was subsequently cross section and metallographically examined. Analysis showed aa few areas of fuel infiltration into the overlapping area, and energy dispersive x-ray spectrometry (EDS) analysis also showed clear distinctions between the zirconium barrier and fuel indicating that there has not been substantial interaction or diffusion of the zirconium foil into the fuel, shown in Figure 17 (Laura Sudderth)

Figure 16. Standard pin cast contained within a 0.002" thick zirconium foil.

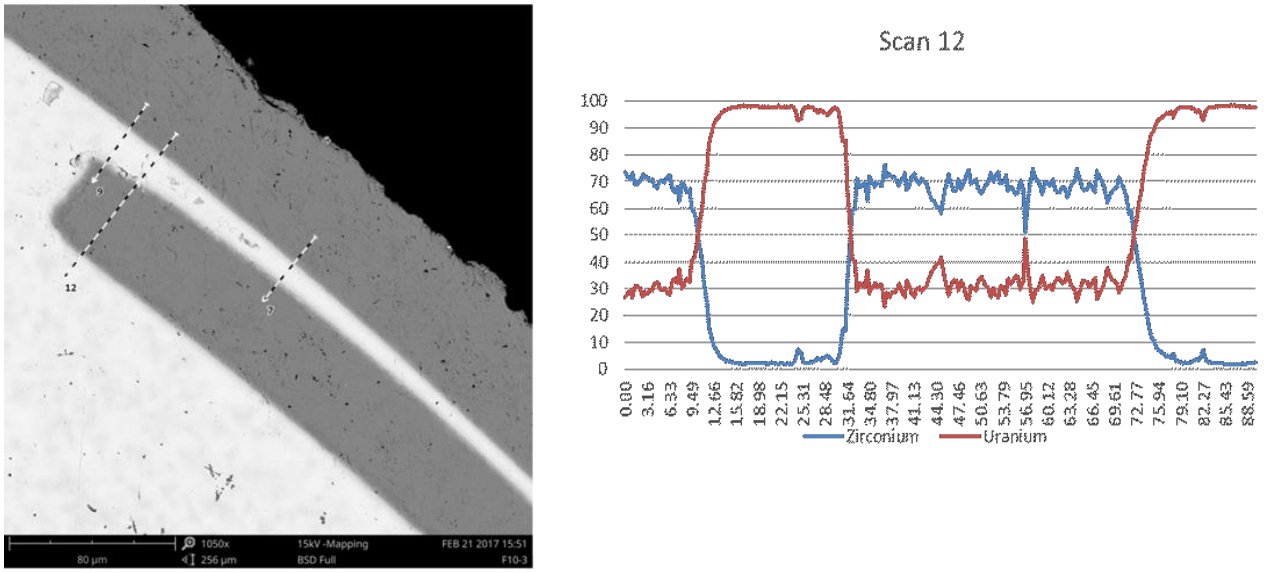


Figure 17. EDS analysis showing clear distinctions between the zirconium barrier and fuel.

- **[INL]** The level 3 milestone to complete the conceptual design of an improved small scale casting system has been completed on schedule. A cut away model of the concept is shown in Figure 18. Nearly all AFC irradiation test and characterization specimens have been cast using the arc casting technique. This technique is very operator and composition dependent and has contributed to significant schedule variation over the years. The new system concept makes use of much of the arc melter hardware as to not increase glovebox footprint, but used induction heating as opposed to an electric arc. The mold will be positioned under the crucible and will also be connected to a vacuum accumulator adding a driving force for a fast flow of material into the mold mitigating compositional effects seen in past arc melting activities. (R. Fielding)

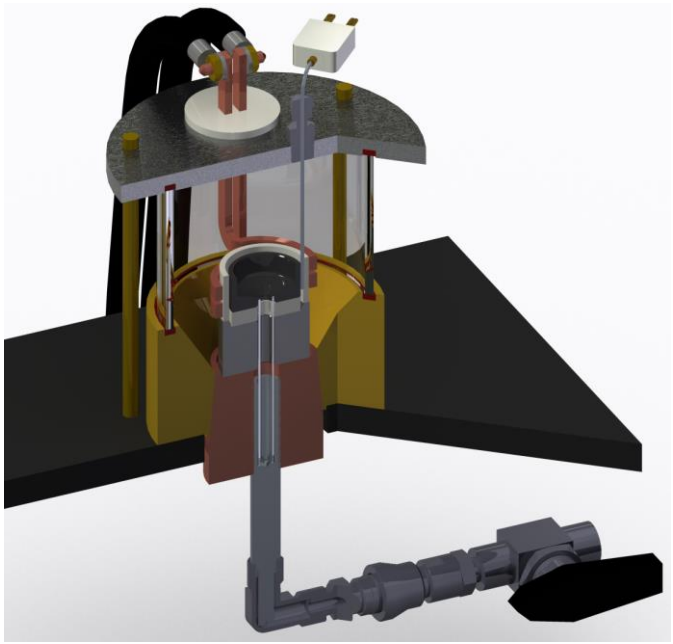


Figure 18. Conceptual design of an improved small scale casting furnace.

- **[INL]** Work has continued in the area of novel optimized fuel compositions. This work includes casting of various alloys using novel alloying agents, diffusion couples, and subsequent characterization, which is reported on under the transmutation fuel work package. Examples of the initial characterization of the U-20Pu-10Zr-3.86Pd-4.3Ln is shown in Figure 19 below. (R. Fielding)

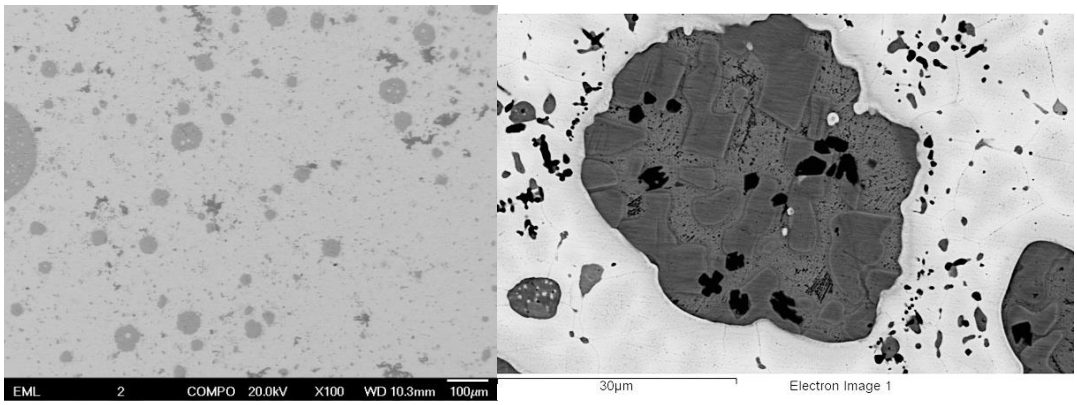


Figure 19. Large area view and magnified image of precipitate showing complex precipitate structure.

AR Core Materials

- **[LANL]** Initial TEM analysis was performed on samples taken from 14YWT tubes irradiated in BOR-60. This data was pulled together into a level 3 report. It provides the first microstructural data measured on the new alloy of 14YWT (FCRD-NFA1) after fast reactor irradiation. (T. Saleh)
- **[PNNL]** Extensive editing has been required for the draft version of Milestone report "M3FT-17PN020302043-Issue Report on Microstructural Studies on Neutron Irradiated MA957 (FY15)". The projected completion date is now early March. (M. Toloczko)

- **[PNNL]** The company making the three 9Cr alloys needed for completion of Milestone "M3FT-17PN020302046" reported that they are having challenges with achieving the target nitrogen levels in two of the alloys. Pieces of the two N-containing alloys were sent to PNNL last month for microstructural observation, and it was found that a moderate density of microvoids were found dispersed throughout the sample. The voids were found to contain TaMnN particles. A piece of the N-free alloy was received this month, and microstructural examination revealed the same microvoids filled with Ta-rich particles. Thus this microvoid issue does not appear to be due to the nitrogen added to the material. We are working with alloy fabricator to resolve this issue, but they have not provided an estimate of when they will have this issue resolved, so this may substantially delay the completion of this milestone. A revised completion data of 04/28/17 has tentatively been selected. (M. Toloczko)
- **[PNNL]** An ion irradiation was completed this month to test the ability for a pure silver layer on the specimen to block carbon ingress. The specimens are expected to arrive back at PNNL in early March and will be examined by APT and SIMS. (M. Toloczko)
- **[LANL]** Tubes of 14YWT ODS material from CEA were manufactured by EDM out of rods they provided. The tubes were then shipped to CWRU to be processed into thin walled tubes. CWRU will use hydrostatic extrusion at 815C to process these tubes as part of the bilateral collaboration with CEA. (S. Maloy)
- **[ORNL]** Two neutron irradiated SS-J2 tensile specimens of 14YWT-SM6 were tested at room temperature in the hot cell at ORNL. These specimens were irradiated in rabbit capsules in HFIR during the Fusion Materials TITAN program at target conditions of 300ºC to ~12 dpa (FD01) and 650ºC to ~16 dpa (FD09). The SiC thermometry indicated that the actual irradiation temperature of the 300ºC target rabbit was ~500ºC while that of the 650ºC target rabbit was estimated to be ~800ºC, but has not been determined from thermometry. The PIE results showed that the FD01 specimen exhibited an increase in the ultimate tensile stress (UTS) of ~210 MPa while the FD09 specimen showed significant softening of -335 MPa compared to the reference unirradiated tensile data. However, both irradiated specimens showed no loss in ductility compared to the unirradiated tensile data (~9% total elongation). The reason for the significant softening of FD09 is not known but may be due to the extended period of 8 cycles (~4,416 h) at ~800ºC in HFIR. The tensile specimen of 14YWT-PM2 will tested next. This specimen was also irradiated in the 300ºC target rabbit. The funding for the PIE tensile tests is provided by NSUF Rapid Turnaround Experiment for the proposal "Neutron Irradiation Effects on Tensile Properties and Deformation Behavior of 14YWT (16-696) that was awarded on August 16, 2016. The PIE results obtained in this study will be a valuable contribution to understanding the radiation tolerance of the microstructure and tensile properties of 14YWT during neutron irradiation. (D. Hoelzer)
- **[ORNL]** The log files containing data recorded by two linear variable differential transformer (LVDT) sensors during the creep tests on MA957 at 825ºC and 70MPa and 14YWT (SM10) at 800ºC and 100 MPa were recovered from the decommissioned computer. The analysis of the data confirmed that the time-to-termination of the creep tests for MA975 was 61,350 h and for 14YWT was 20,327 h. However, after converting the LVDT data into strain, plots of strain versus time for both alloys showed that after reaching a strain of ~0.27-29% during primary creep, the creep rate during secondary creep was slightly negative until reaching a final strain of ~0.25% at the termination of the creep tests. This negative secondary creep rate behavior is very unusual and apparently, no mechanisms can explain these results. The grain size and porosity of the MA957 samples used in the six completed creep tests were measured. The results show that grain coarsening did not occur in any of the samples after the creep tests compared to as-received MA957 sample. The pore size, area fraction and area density depended on the creep conditions. The pores that formed in the sample tested at 825ºC and 70 MPa for 61,350 had the largest size, area fraction and area density compared to

the 5 other samples. These results show that while the grain structure and nano-size oxide dispersion present in MA957 are very resistant to coarsening, the porosity that forms in the microstructure during creep at elevated temperatures and stresses represents an instability that may be linked to the failure mechanism of MA957. (D. Hoelzer)

- **[PNNL]** The fracture testing procedure for irradiated small specimens was updated to reflect the new experience of facility operation in last year at Radiochemical Processing Laboratory (RPL). Details in fracture testing steps, such as cyclic loading conditions in precracking and final fracture and optical fractography procedure, were further established and added in the revision of the RPL testing facility operation procedure (SOP-SFO-225). Further, the Test Instruction for fracture testing, which usually is used by test technicians, was revised accordingly and distributed for internal review (T. S. Byun)
- **[PNNL]** As part of the program to fabricate tubing from difficult-to-fabricate materials, MA956, 9YWT, and 14YWT are being extruded and pilgered to final dimensions. A second thick-wall 14YWT tube has been successfully extruded. The extrusion parameters and characteristics for the second extrusion were similar to those of the first, and so repeatability was demonstrated. The second extrusion, immediately after extrusion and prior to cleanup, is shown in Figure 20 below. (C. Newsom)

Figure 20. Second thick-wall 14YWT tube extrusion prior to cleanup.

AR Irradiation Testing & PIE Techniques

- **[INL]** All required analysis and paperwork for the shipment of experiments AFC-3C and AFC-3D to the Hot Fuels Examination Facility for Post Irradiation Examination (PIE) have been completed and the shipment has been loaded into the GE-100 shipping cask. This shipment will support timely commencement of PIE. (D. Dempsey)
- Neutron radiography was performed using the HFEF NRAD reactor (Figure 21). X501-G591 is one of the kind pin fabricated by injection casting and irradiated in EBR-II that contains a few wt% of MA (Np, Am). Full PIE will be of incredible value in comparison with others MA bearing metallic fuel such as AFC-1 and FUTURIX-FTA. (J. Harp)

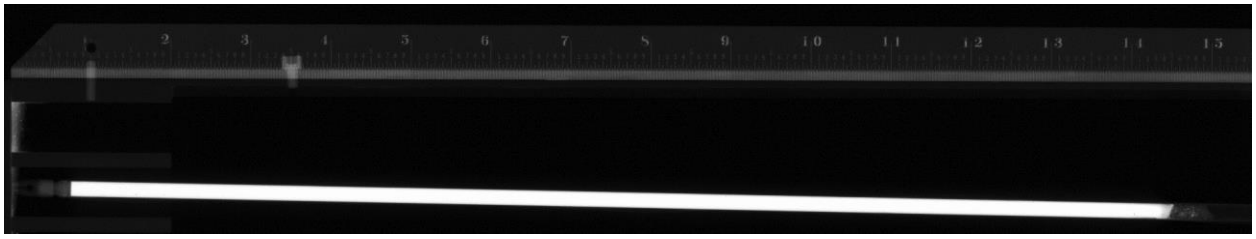


Figure 21. Thermal neutron radiography image of the fuel slug from X-501 G591.

- **[INL]** A subcontract was issued to bring out SCK-CEN experts to repair and troubleshoot the BONA4INL dimensional inspection bench. This repair will allow dimensional inspection of rodlets. (J. Harp)

CAPABILITY DEVELOPMENT

Fuels

- **[INL]** The instrument for remote measurement of the thickness of thin transducer films used with the TCM has been fabricated and assembled. The optical fiber feedthroughs for the glove box and extended length optical fiber delivery cables have been ordered. The MFC Laser Safety Officer has completed calculations pertaining to safe operation of the lasers at FCF and shielding requirements have been identified. These requirements have been discussed with the facility management and formal documentation has been submitted. Work is continuing on a glovebox compatible stand for the TCM which will integrate the TCM, sample stages and thickness monitor. The instrumentation rack which will house the external electronic equipment is being assembled. A stage motor has been ordered for compatibility testing in an argon environment and we are continuing to work with vendors on this issue. (D. Hurley)

Irradiation, Testing, and PIE

- **[INL]** Planning began for next APS beamline experiments with IIT, INL, and Purdue. Specimens to be measured this summer at APS were communicated to NSUF. Progress was made on analysis of EXAFS data and training of students. (M. Okuniewski)

For more information on Fuels contact Jon Carmack (208) 533-7255.

MATERIAL RECOVERY AND WASTE FORMS DEVELOPMENT

CAMPAIGN MANAGEMENT AND INTEGRATION

- **[INL]** A joint workshop on modeling and simulation between the MPACT and MRWFD campaigns was held in Phoenix, AZ. The two-day workshop covered needs in modeling and simulation to support separation process development, demonstration and operation, as well as implementation of safeguard methods. The meeting discussed modeling and simulation needs for both aqueous and electrochemical processing. This meeting will form the basis for a new joint modeling and simulation initiative, proposed for funding in FY-18. (T. Todd)
- **[PNNL]** A ceramics waste form topical meeting was held on February 13th. Representatives from national laboratories (LANL, PNNL, and SRNL) and universities (Alfred and Clemson) presented their scope, results, impacts, issues, and plans related to glass ceramics waste forms. Collaborative research was also discussed between all the performing organizations and DOE. (J. Vienna)

INTERNATIONAL COLLABORATIONS

- **[ORNL, INL]** Representatives from DOE-NE, ORNL and INL traveled to China to continue and expand opportunities in the US-China Bilateral Civil Nuclear Energy Collaboration. First time visits to Tsinghua University, Institute of Nuclear and New Energy Technologies as well as the Institute of High Energy Physics were held to meet staff and discuss research interests. An advanced separations working group meeting was held at the China Institute of Atomic Energy to discuss ongoing collaborations. (T. Todd)

REFERENCE TECHNOLOGIES AND ALTERNATIVES

- **[INL]** The milestone M3FT-17IN030102013 titled, "Analysis of samples generated from the test loop irradiations of the ALSEP process," was completed. The completion of this milestone was documented in a formal report (NTRD-MRWRD-21017-000151). The impact of gamma radiolysis upon the efficacy of the ALSEP process was previously evaluated by determining americium, europium, and cerium distribution ratios as a function of absorbed dose using samples taken from test loop irradiations performed during FY-2016. The measured distribution ratios demonstrated that the ALSEP solvent performance was degraded by gamma-irradiation. The recently completed compositional analysis of the irradiated ALSEP solvent samples revealed that the decrease in americium, europium, and cerium distribution ratio with increasing absorbed dose is primarily attributable to the loss of the T2EHDGA extractant due to radiolytic degradation. The analysis of the irradiated ALSEP samples demonstrated that the neutral HEH[EHP] extractant did not experience significant radiolytic degradation. However, the phosphonic acid formed by cleavage of the ester bond of HEH[EHP] was detected and its concentration increased as a function of absorbed gamma-dose. Additionally, the analysis of samples from the hydrolysis test performed in the test loop show no statistically significant change in the concentration of the components of the ALSEP solvent occurred. This finding is consistent with the distribution ratios determined for the same sample set, which showed no dependence of the measured distribution ratios upon the amount of time the ALSEP solvent was contacted with 4 M nitric acid in the test loop. (D. Peterman)
- **[ORNL]** The design of the main components of the recirculation loop is complete, and all items are being fabricated. Cold testing of the reactor and mixer revealed the need for minor equipment modifications. The vendor doing this modification reported a delay of 2-3 weeks due to problems with their milling machine. Currently, no delays on the related milestone are expected. The Milestone M3FT-17OR030102033 "Complete design and assembly of main components of recirculation loop" due on 5/16/2017 is forecast to be on time. (B. Jubin)

- **[ORNL]** Coordination meetings with 3525 are also underway. The safety basis of the 3525 facility was modified and a new screening of the project based on the new regulations has begun. No substantial implication is expected toward our planned activities but this still requires an official response by the Non-Nuclear-Facilities Division of ORNL (B. Jubin)
- **[ORNL]** The milestone report for this task, M3FT-17OR030102026, was completed and distributed. This report describes the synthesis and evaluation of molecular sieve zeolite membranes to separate and concentrate tritiated water (HTO) from dilute HTO-bearing aqueous streams. Several monovalent and divalent cation exchanged silico alumino phosphate (SAPO-34) molecular sieve zeolite membranes were synthesized on disk supports and characterized with gas and vapor permeation measurements. The pervaporation process performance was evaluated for the separation and concentration of tritiated water. The reported experimental data showed HTO/H_2O selectivity and separation factor calculated from the measured tritium concentrations ranged from 0.99 to 1.23, and 0.83-0.98, respectively. Although the membrane performance for HTO separation was lower than expected, several encouraging observations including molecular sieving and high vapor permeance are reported. Additionally, several new approaches are proposed, such as tuning the sorption and diffusion properties offered by small pore LTA zeolite materials, and cation exchanged aluminosilicates with high metal loading. It is hypothesized that substantially improved preferential transport of tritium (HTO) resulting in a more concentrated permeate can be achieved. Preliminary economic analysis for the membrane-based process to concentrate tritiated water is also discussed. (B. Jubin)
- **[ORNL]** Effort is now focused on synthesis of improved cation exchange zeolite membranes. For this purpose, aluminosilicate zeolites such as Na-LTA (Linde Type A) will be synthesized and characterized for their permeance and ion exchange properties. It is anticipated that these hydrophilic small pore zeolite membranes will improve the HTO permeance and selectivity. It is estimated that compared to silicoalumino phosphates (SAPO), which have limited ion exchange sites (0.1-0.2 cations/Al atom), LTA zeolites can provide superior cation exchange capacity (1 cation per aluminum atom). Further, when exchanged with potassium, the pore size of the zeolite framework can be reduced. Sample characterization is currently in progress, and evaluation of samples for the separation of tritiated water will begin in March. (B. Jubin)

SIGMA TEAM FOR ADVANCED ACTINIDE RECYCLE

- **[INL]** Planning for a single stage contactor test based on the U/DAAP test performed in January using AmVI was completed. This test will be performed in March. A batch of DEHBA was also synthesized by John Klaehn at INL, in an effort to prepare better material than is available commercially. Batch contacts showed DAm ~ 5, which is a good result for a possible DEHBA hot test later this year. Discussions are underway now to have a larger batch of this material synthesized to support such a test. Batch extraction studies were also initiated last month to address issues with Ru oxidation interference and post-contact aqueous re-oxidation problems. (B. Mincher)
- **[ORNL]** A paper was accepted for publication in the Gatlinburg Meeting Special Issue of *Separation Science & Technology* titled, "Separation of Americium from Europium using 3,3'-dimethoxy-phenyl-bis-1,2,4-triazinyl-2,6-pyridine," Talon G. Hill, Ai Lin Chin, Serene Tai, Jesse D. Carrick, Dale D. Ensor, and Lætitia H. Delmau. This work demonstrates the efficacy of a nitrogen-based bis-triazinyl pyridine (BTP) derivative to selectively extract Am(III) from nitric acid solutions containing light lanthanides. The aromatic-substituted BTP 3,3'-dimethoxy-phenyl-bis-1,2,4-triazinyl-2,6-pyridine was shown to be a more efficient Am(III) extractant in a polar diluent in comparison to a camphor substituted BTP under comparable conditions. (B. Moyer)
- **[ORNL]** New aqueous complexants that feature faster kinetics with comparable selectivity and binding strength in comparison with DTPA for the ALSEP process are being sought through

synthesis, spectroscopy, thermodynamics, and extraction testing. Ab initio molecular dynamics (MD) simulations are being carried out for several tens of picoseconds starting from several different configurations for one of the candidates in which a carboxylate sidearm had been replaced by an alcohol sidearm. Additionally, free energy simulations using the metadynamics approach are being employed to identify the most probable coordination number. The results will have important implications for the design of new ligands with improved complexation kinetics. (B. Moyer)

SIGMA TEAM FOR OFF-GAS CAPTURE AND IMMOBILIZATION

- **[INL]** Iodo-dodecane was identified as a good surrogate for long-chained organic iodides that could be formed during aqueous used fuel reprocessing and will be used for upcoming iodine adsorption experiments. VICI Metronics, a vendor for permeation tube systems, developed and provided commercial NIST-traceable iodo-dodecane permeation tubes for use in the iodine adsorption testing. Work control documentation was updated to ensure data quality, worker safety, environmental protection, and regulatory compliance while using and storing iodo-dodecane. The iodo-dodecane permeation tubes from VICI Metronics have been successfully tested in the INL deep-bed iodine adsorption test system. Iodo-dodecane samples were detected in the gas chromatograph with flame ionization detection, which is also used for methyl iodide analysis. The retention time was about 12.5 minutes. (N. Soelberg)
- **[ORNL]** The milestone report for design of a tritium and iodine removal system for use with advanced tritium pretreatment, M4FT-17OR030107025, was completed on schedule. The off-gas stream generated by advanced TPT will contain iodine, tritium, high levels of NO_2, and other volatile and semi-volatile radionuclides contained in UNF, including $^{14}CO_2$, ^{85}Kr, and Xe. As part of the FY18 demonstration, off-gas treatment methods for the advanced tritium pretreatment off-gas (ATPOG) to recover tritium and iodine, separate from one another, will be developed and demonstrated. This report is intended to assess the stream and identify potential treatment approaches that could sequester iodine and tritium from ATPOG. Preliminary system designs are provided as a first-step towards the development of the system intended for use in the kilogram-scale demonstration. A number of materials were identified as potential nitric acid or water sorbents. For nitric acid, removal would be conducted at lower temperatures and sorbents to be tested include nylon fibers, silica gel, and 5A molecular sieves. For water removal at high temperatures, 3A molecular sieves and silica gel were identified as candidate materials. Scoping tests on each of these sorbents will be completed in FY17. The composition of the ATPOG is unique given its high NO_2 concentration, and thus data on these potential tritium sorbents are largely unavailable for applicable conditions. (B. Jubin)
- **[ONRL]** The milestone report for "Fundamental Aspects of Iodine Containing Zeolite Waste Form Production by Hot Isostatic Pressing," M3FT-16OR030107027 has been completed and was issued on Feb 6. A set of 16 samples were produced, HIPed, and analyzed by X-ray diffraction (XRD). The zeolites under investigation included silver-exchanged zeolite Type A (AgA), silver-exchanged faujasite (AgX), silver-exchanged mordenite (AgZ), and sodium mordenite (NaZ). HIP pressures ranged from 175 to 300 MPa. Iodine was incorporated into the zeolite material through either occlusion or chemisorption at varying iodine: zeolite ratios. One of the most significant observations from the completed work was that no iodo-sodalite formation was observed for any of the I-AgZ samples, either chemisorbed or occluded. This is likely tied to the relative amounts of silicon and aluminum present in AgZ as compared to AgA and AgX. The silicon-to-aluminum ratio (Si: Al) for the mordenite unit cell is five times that of AgX and AgA. The importance of this characteristic was first identified by Sheppard et al. (2006) and has been reinforced through this study.

  Throughout the course of the testing described in this report, and through previous efforts, attention has been given to optimizing the pressing conditions for Ag-zeolite samples. Temperatures have ranged from 525–1100°C, and pressures have ranged from 75–300 MPa. This work used pressures of

175, 190, and 300 MPa. No difference (either visually or through XRD) was identified that could be correlated to pressure conditions. Further characterization, such as through waste form durability testing, would be required to fully describe the effect of pressure on HIPing of iodine-loaded zeolite minerals. (B. Jubin)

- **[ORNL]** Two tests were completed for the task, "Effect of iodine concentration on the removal of iodine from VOG streams by AgZ." The first test was 0.64 weeks in duration with a CH_3I concentration of 1000 ppmv in a feed stream with 0°C dew point. The second test was 1.6 weeks in duration with a CH_3I concentration of 400 ppmv in a feed stream with 0°C dew point. NAA results of iodine loading for these tests are pending. In addition, permeation tubes containing CH_3I have been ordered and received. Tests with these will be initiated in early March. (B. Jubin)
- **[ORNL]** Permeation tubes for methyl iodide delivery were ordered and received for the task, "initiate comparison of AgZ and AgAerogel performance under VOG conditions." This delivery method was necessitated by the anomalous behavior of the CH_3I/N_2 cylinders that were in use previously. No VOG tests have yet been conducted with the new delivery method. A new VOG test system was constructed that reduces the likelihood of leaks in the system and increases the ease of assembly (Figure *22*). (B. Jubin)

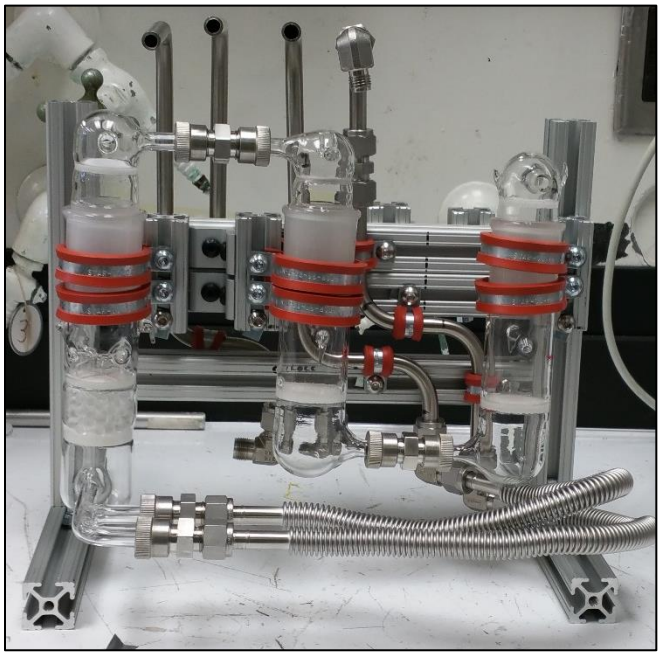


Figure 22. New VOG test system which reduces the likelihood of leaks and increases the ease of assembly.

- **[ORNL]** Two ~10 g samples of 3A molecular sieve were aged in a 75% NO_2 environment at 40°C for the stability of tritium adsorbent and iodine sorbent in TOG conditions and system design task. The first sample was aged for 3 weeks and the second sample was aged for 4 weeks. The material will be characterized by SEM, XRD, and for total water capacity. (B. Jubin)
- **[ORNL]** Four tests with the aqueous scrubber system that will recover the tritium released from the Zr recycle tests were completed in February. The first two were replicate tests intended to determine the efficiency of the scrubber with a simulant feed stream. The scrubber solution was H_2O and the feed concentration of DCl was 2% v/v in a 10% Cl_2(bal Ar) feed stream. The third test was intended to provide insight into the dependence of H_2O scrubber performance on DCl concentration and used a feed stream containing 0.5% DCl v /v in a 10% Cl_2(bal Ar) feed stream. The fourth test utilized DCl

only (no diluent feed stream) and will be used as a reference point for the H_2O scrubber. Samples of all scrubber solutions were collected and will be sent for isotopic analysis to determine scrubber efficiency. (B. Jubin)

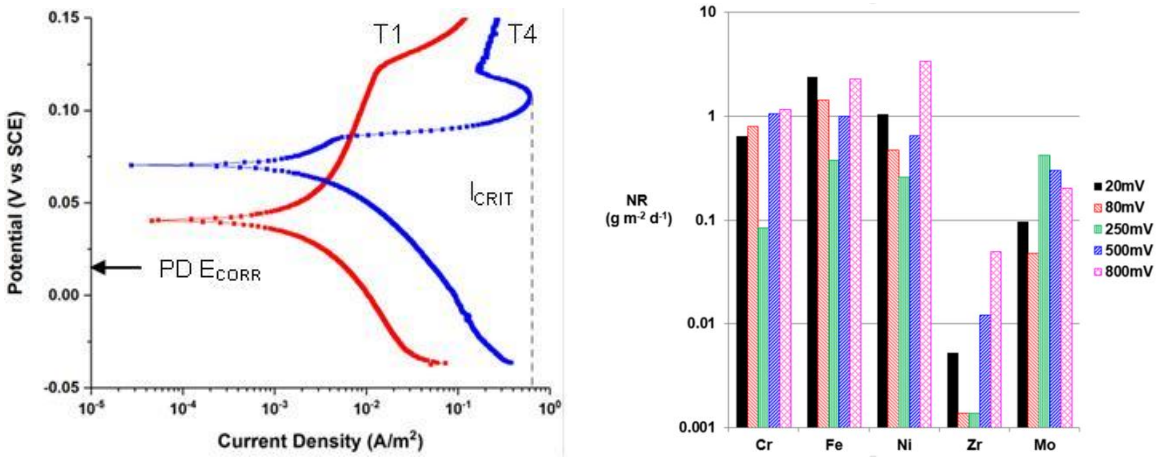
FUNDAMENTAL SEPARATION DATA/METHODS

- **[INL]** A manuscript titled, "The reactivity of the nitrate radical (NO3) in aqueous and organic solution," was submitted to *J. Phys Chem*, in completion of milestone M3FT-17IN030104033. This paper summarizes NO3 radical reaction data collected under this program since 2010, including kinetics in aqueous and organic media, and methods for the production of the radical in those media. The series of compounds investigated allowed for elucidation of mechanisms and some discussion of structure activity relationships for the reactions. (B. Mincher)
- **[INL]** A manuscript titled "Radiation chemistry of the branched-chain monoamide di-ethyl-hexyl-isobutyramide," written in collaboration with co-workers at CEA in France, was submitted for publication to the journal *Solvent Extraction and Ion Exchange*. This paper summarizes the findings of FY16 work with CEA on monoamide radiolysis. (B. Mincher)

WASTE FORM DEVELOPMENT AND PERFORMANCE

Electrochemical Waste Forms

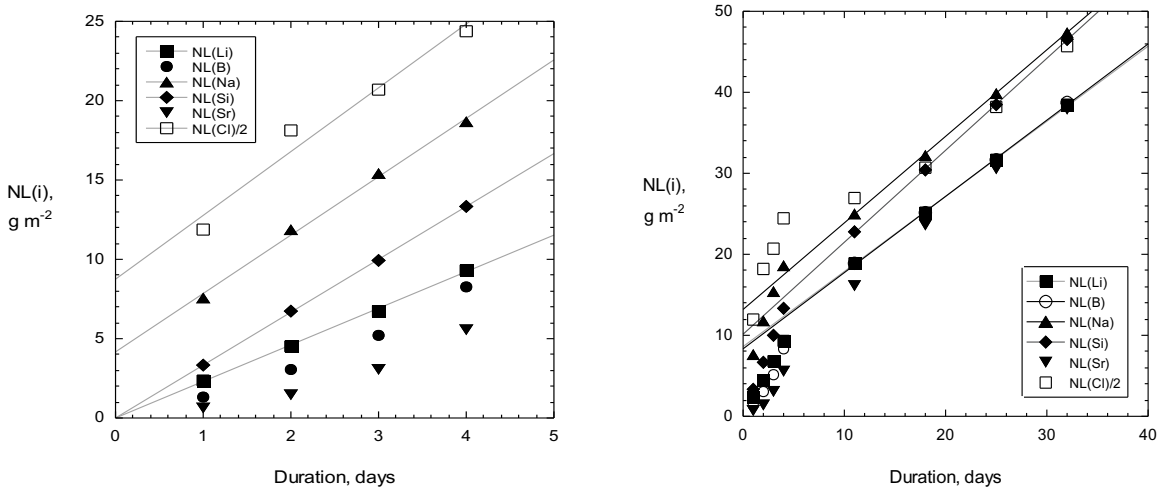
- **[ANL]** Electrochemical tests with alloyed waste form materials remain in progress to support development and parameterization of a degradation model for calculating waste form performance. An important aspect is providing confidence in applying short-term test results to long-term behavior. This is being done combining electrochemical measurements with microscopic and solution results. For example, Figure *23*a shows Tafel scans after the surface stabilized at open circuit (T1 red curve) and after it re-stabilized at an applied 0.25 V (T4 blue curve) to represent radiolytic oxidation. The arrow indicates the corrosion potential of the bare surface measured in a potentiodynamic scan (PD), and the red curve shows the surface had stabilized at open circuit to increase Ecorr to about 0.04 V; the sharp point in the curve where the current density is minimum locates Ecorr. This is due to formation of MoO_2. Further stabilization at 0.25 V occurs as a Cr_2O_3 passive layer form and Ecorr increases to about 0.07 V. The large "nose" centered at about 0.10 V in the Tafel scan T4 blue curve giving a critical current density of about 0.7 A/m^2 is attributed to the leaching of Mo from the surface during corrosion at the applied 0.25 V. Figure *23*b shows solution results after tests at different potentials. The Mo concentrations reflect the formation of MoO_2 in tests at 20 and 80 mV and the formation of $NiMoO_4$ at 500 and 800 mV, and the greatest Mo release at the intermediate potential of 250 mV. The degradation model for alloyed waste forms utilizes the combination of electrochemical theory with microscopic and solution analyses to establish the scientific basis, provide analytical functions and parameter values to quantify environmental and waste form composition effects, and provide confidence in model calculations. (W. Ebert)



(a) (b)

Figure 23. (a) Tafel scans before and after potentiostatic hold at 250 mV and (b) solution results after tests at different applied voltages.

- **[ANL]** Corrosion tests with an advanced ceramic waste forms made with LiCl/SrCl2 waste salt and binder glass N4 have been completed. Figure 24a and b show results of ASTM C1308 tests conducted to determine if waste salt constituents are contained in sodalite or the glass binder, and if they are leached or released congruently with the host phase. The normalized mass loss values are constant in tests with daily and weekly exchanges, which indicate dissolution-controlled release of elements from the sodalite (Na, Si, and Cl) and glass (B, Li, Na, Si, and Sr) phases. The positive y-intercepts for NL(Na) and NL(Cl) indicate a small amount of halite (NaCl) is formed, but the Li and Sr in the salt was completely accommodated in the ACWF. A report summarizing the production and testing of ACWF materials is being prepared. (W. Ebert)



(a) (b)

Figure 24. Results of ASTM C1308 tests with ACWF ORH2 showing (a) 1-day exchanges and (b) 7-day exchanges

Ceramic Waste Forms

- **[LANL]** Ming Tang attended the Ceramic Waste Forms webinar and updated the progress of this work package. (M. Tang)
- **[SRNL]** The manuscript titled, "Cold Crucible Induction Melter Test for Crystalline Ceramic Waste Form Fabrication: A Feasibility Assessment," J. W. Amoroso, J. Marra, C. S. Dandeneau, K. Brinkman, Y. Xu, M. Tang, V. Maio, S. Webb and W. K. S. Chiu,, was published in *J. Nucl. Mater.*, 486 pp. 283-297, (2017). http://dx.doi.org/10.1016/j.jnucmat.2017.01.028 (J. Amoroso, P. Smith)

Glass Ceramics Waste Forms

- **[LANL]** Ming Tang attended the Glass Ceramic Waste Forms webinar and updated the progress of this work package. To investigate irradiation effects on static leaching test glass ceramic samples, plan-view SEM observation was performed on a pristine sample before leaching test, non-irradiated sample after 7 and 28 days leaching test, and irradiated sample after 7 and 28 days leaching test. The next step is to do cross-sectional SEM and TEM observation on these samples, to explore crystal structure and chemical evolution. (M. Tang)
- **[PNNL]** The individual phases observed in the glass ceramic centroid composition have been successfully synthesized: powellite, oxyapatite, and remainder glass composition. Powellite was prepared by melting at 1500°C followed by slow cooling at 1°C/min to crystallize into a dense polycrystalline ceramic. Oxyapatite was synthesized by the sol-gel approach, followed by traditional ceramic processing (calcining, ball milling, cold isostatic pressing, and firing) to produce 94% dense polycrystalline ceramic pellets. The remainder glass composition was made with the noble metals removed. (J. Crum)
- **[SRNL]** Vessels were sampled in late February and analytical data is expected in March (C. Crawford, P. Smith)

Zirconium Recycle

- **[ORNL]** The milestone report for this task, M3FT-17OR030102026, was completed and distributed. This report describes the synthesis and evaluation of molecular sieve zeolite membranes to separate and concentrate tritiated water (HTO) from dilute HTO-bearing aqueous streams. Several monovalent and divalent cation exchanged silico alumino phosphate (SAPO-34) molecular sieve zeolite membranes were synthesized on disk supports and characterized with gas and vapor permeation measurements. The pervaporation process performance was evaluated for the separation and concentration of tritiated water. The reported experimental data showed HTO/H_2O selectivity and separation factor calculated from the measured tritium concentrations ranged from 0.99 to 1.23, and 0.83-0.98, respectively. Although the membrane performance for HTO separation was lower than expected, several encouraging observations including molecular sieving and high vapor permeance are reported. Additionally, several new approaches are proposed, such as tuning the sorption and diffusion properties offered by small pore LTA zeolite materials, and cation exchanged aluminosilicates with high metal loading. It is hypothesized that substantially improved preferential transport of tritium (HTO) resulting in a more concentrated permeate can be achieved. Preliminary economic analysis for the membrane-based process to concentrate tritiated water is also discussed. (B. Jubin)
- **[ORNL]** The effort is now focused on synthesis of improved cation exchange zeolite membranes. For this purpose, aluminosilicate zeolites such as Na-LTA (Linde Type A) will be synthesized and characterized for their permeance and ion exchange properties. It is anticipated that these hydrophilic small pore zeolite membranes will improve the HTO permeance and selectivity. It is estimated that compared to silicoalumino phosphates (SAPO), which have limited ion exchange sites (0.1-0.2

cations/Al atom), LTA zeolites can provide superior cation exchange capacity (1 cation per aluminum atom). Further, when exchanged with potassium, the pore size of the zeolite framework can be reduced. Sample characterization is currently in progress, and evaluation of samples for the separation of tritiated water will begin in March. (B. Jubin)

Advanced Waste Form Characterization

- **[ANL]** Electrochemical tests with AgI are in progress to characterize the dissolution kinetics over a range of Eh and pH conditions. Initial tests measured the dissolution rates of pure AgI as a function of Eh and pH to provide a data base of evaluating the performance of waste forms in which AgI particles are embedded in inert matrices have been completed. New tests have been started to measure the AgI dissolution rate in various $FeBr_2$ solutions that provide a range of solution Eh values. Initial tests are being conducted using AgI electrodes for direct correlation with the tests just completed. These will be followed by tests using AgI powder and then AgI embedded in silicate and zeolite matrices. The electrochemical approach provides the sensitivity required to measure the dissolution kinetics, which cannot be attained by chemical methods. (W. Ebert)
- **[ANL]** W. Ebert met with colleagues at PNNL to discuss strategy for the upcoming meeting with the NWTRB to discuss waste glass modeling. (W. Ebert)
- **[ANL]** Modified PCTs using leachants prepared with different Al, Si, and pH have been started to measure their effects on triggering Stage 3 and the Stage 3 rates of AFCI and LRM glasses. These results will be used to derive composition thresholds used in the ANL Stage 3 model. (W. Ebert)
- **[PNNL]** Scientists utilized time at the Advanced Photon Source to obtain comparative Small Angle X-ray Scattering (SAXS) data (Figure 25) on corrosion induced and synthetically produced gels of the same composition. Additionally, the structure of both material types dependent on pH was evaluated. The gel structures have not been characterized to this level in a comparative fashion before. (J. Ryan)

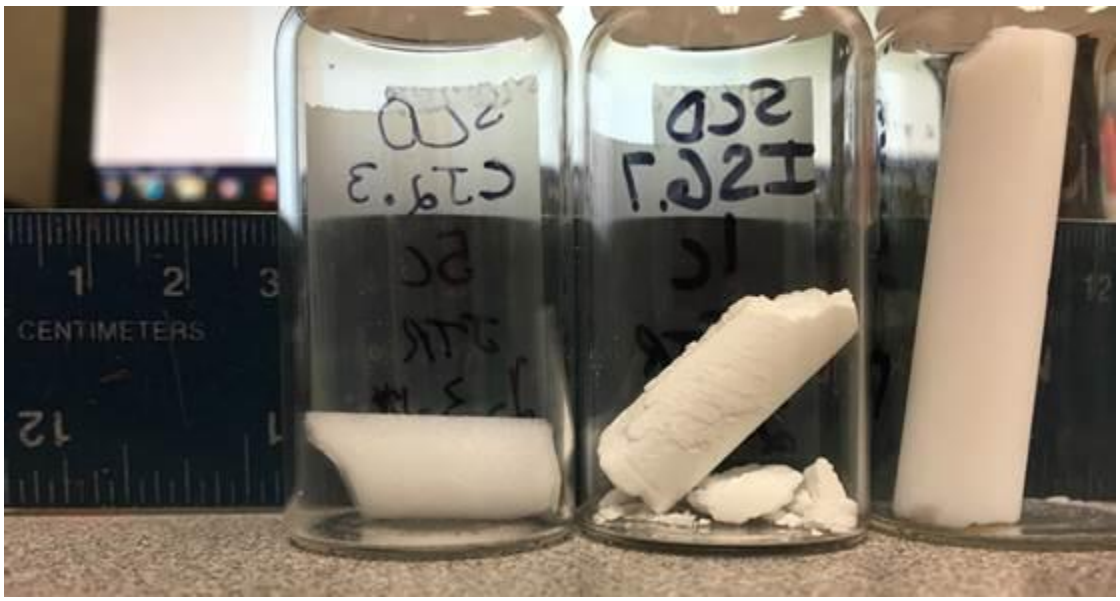


Figure 25. From left to right, synthetically produced gels at pH 3, pH 7, and pH 9 that were analyzed at the Advanced Photon Source to obtain SAXS data.

DOMESTIC ELECTROCHEMICAL PROCESSING

- **[ANL]** Co-deposition tests under controlled current conditions show that as the deposit increases in size, the potential of the co-deposition cathode vs. reference gradually becomes less cathodic. Fortunately a simple linear increase in applied current is able to maintain a constant potential at the co-deposition cathode. Current interrupts are also being evaluated as a method for correcting the co-deposition cathode potential for iR effects. (J. Willit)
- **[INL]** Work in support of milestone "M3FT-17IN030106021 – MASTERS: ASC Module" is well underway. The purpose is to incorporate experience with the Advanced Solid Cathode (ASC) studies into the MASTERS code and compare the modeled performance of the Liquid Cadmium Cathode (LCC) to the ASC with respect to separations between actinides and lanthanides. Figure 26 below shows the Excel-based user interface incorporating the ASC module into one version of the MASTERS pyroprocessing flowsheet. (G. Fredrickson)

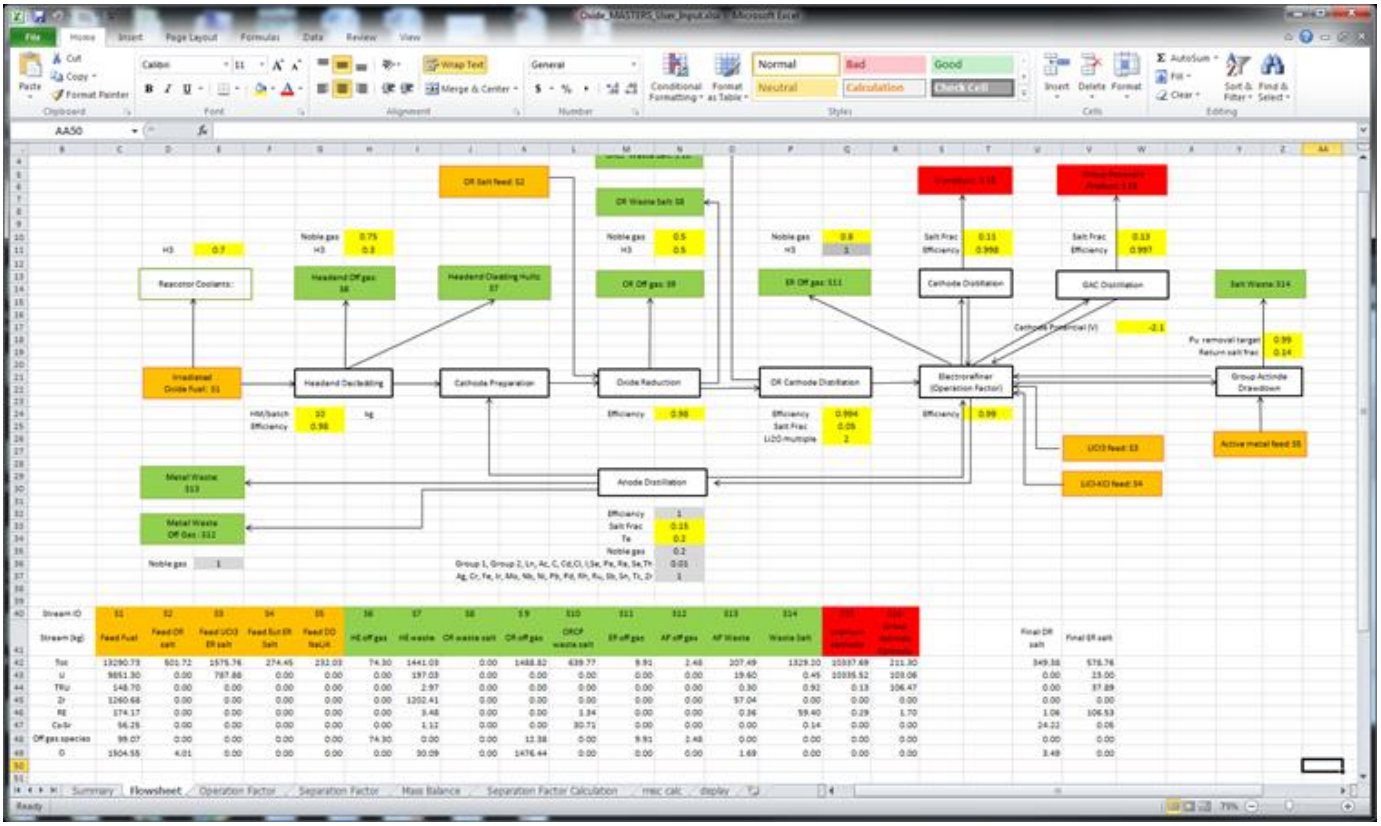


Figure 26. Excel-based user interface incorporating the ASC module into one version of the MASTERS pyroprocessing flowsheet.

- **[INL]** Work in support of milestone "M3FT-17IN030106022 – Technology-Gap Study" is underway. This is a follow-on study to milestone "M3FT-17IN03010602 – FY16 Technology-Gap Study" which was completed earlier. The earlier study examined the relationship between uranium recovery and zirconium retention in the anode basket during electrorefining of Experimental Breeder Reactor II (EBR-II) and Fast Flux Test Facility (FFTF) driver fuels in the Mk-IV electrorefiner in the Fuel Conditioning Facility (FCF). The latter study will examine similar relationships between uranium recovery and the retention of select transuranics and lanthanides. These data, based on the historical

performance of the Mk-IV electrorefiner, will be used to improve the reliability of the MASTERS pyroprocessing flowsheet modeling code. (G. Fredrickson)

- **[INL]** Work in support of milestone "M3FT-17IN030106023 – Electrochemical Measurements" is being performed at the Center for Advanced Engineering Studies (CAES) Radiochemistry Laboratory (RCL). This effort will use non-radiological surrogates to mimic the behavior of uranium and plutonium chlorides (in electrorefiner slats) to study the performance of the advanced solid cathode (ASC) in the lower concentration regions of uranium chloride where it is proposed that cathodic potential control will be more manageable. An individual technical report for each milestone will be issued later in FY2017. (G. Fredrickson)

FUEL RESOURCES

- **[ORNL]** Electrospinning has been used at ORNL to generate a fiber mat adsorbent made of nanoscale fibers. Samples have been sent to LCW for further processing and subsequent testing with natural seawater at the Marine Sciences Laboratory of PNNL. (C. Janke)
- **[ORNL]** U.S. personnel working on the DOE Fuel Resources Program including Drs. Stephen Kung (DOE-NE), Gary Gill (PNNL), Chris Janke (ORNL), Richard Mayes (ORNL), and Carter Abney (ORNL) participated at the Extraction of Uranium from Seawater Information Exchange Meeting under the auspices of the Japan-U.S. Civil Nuclear Energy R&D Working Group in Takasaki, Japan, on February 16-17. During this meeting, Chris Janke provided an update on "Adsorbents Prepared by Radiation Induced Graft Polymerization" and Carter Abney presented on "Identifying Metal Binding Environments through Advanced Spectroscopic Techniques". (R. Mayes, C. Janke, C. Abney)
- **[ONRL]** New solution reactions of vanadium have been provided by Dr. Rao of LBNL, and computational results of stability constants for vanadium complexes obtained for the two representative ligands, acetamidoxime (HAO) and cyclic imide-dioxime (H_3IDO), have been obtained for comparison with experimental data. A very good agreement was observed between theoretical calculations and experimental data. (V. Bryantsev)
- **[ORNL]** A correlation between polymer length and uranium coordination environment has been identified. This is, to the best of our knowledge, the first time such behavior has been investigated and observed. (C. Abney)
- **[ORNL]** Two articles have been published on journals websites as shown below (C. Tsouris):

– Tsouris, C. "Extracting Uranium from Seawater," Nature Energy, 2, 17022, http://dx.doi.org/10.1038/nenergy.2017.22, February, 2017. This article discusses a paper from the Stanford University team, published in the same issue of Nature Energy, in relation to the overall effort on uranium recovery from seawater.

– Ladshaw, A.P.; Kuo, L.-J.; Strivens, J.E.; Wood, J.R.; Schlafer, N.J.; Yiacoumi, S.; Tsouris, C.; Gill, G.A., "Influence of Current Velocity on Uranium Adsorption from Seawater Using an Amidoxime-Based Polymer Fiber Adsorbent," Industrial & Engineering Chemistry Research, http://dx.doi.org/10.1021/acs.iecr.6b04539, February, 2017. This paper is the result of a collaboration between PNNL, ORNL, and Georgia Tech and describes the influence of seawater currents on uranium adsorption by amidoxime functionalized polyethylene fibers in columns and in flumes with the adsorbent in the form of braids.

- **[PNNL]** Gary Gill traveled to Japan on February 14-19 to participate in a joint DOE – QST (National Institute for Quantum and Radiological Science and Technology) technology exchange on the topic of extraction of uranium from seawater. The meeting was held at the Takasaki Advanced Radiation Research Institute in Takasaki, Japan. Also attending from the US were Chris Janke, Richard Mayes,

and Carter Abney from Oak Ridge National Laboratory. The US team was headed by Dr. Stephen Kung of DOE-NE. Gary provided an update on the marine testing program at PNNL. (G. Gill)

- **[PNNL]** A new set of experiments were started in February to assess the impact of elevated dissolved organic carbon and iron concentrations on the adsorption capacity of uranium on amidoxime-based adsorbents. PNNL found some preliminary evidence in previous studies that DOC levels may affect adsorption capacity by coating the adsorbent and blocking access of the uranium in seawater to binding sites. Also, iron is one of the dominate elements retained on amidoxime-based adsorbents and can exist in high concentrations in some coastal environments. Hence, understanding the impact of this element on adsorption capacity of uranium is warranted. (G. Gill)
- **[Stanford]** Fuel Resources, FT- 17SL03020106, A new type of sorbent material has been synthesized and being investigated for U extraction using electrochemical method. More electrochemical tests are being carried out. (C. Liu)

CoDCon Demonstration

- **[ANL]** A presentation was made at the joint MPACT-MRWFD mod/sim roadmapping meeting held in Phoenix AZ on the capabilities of AMUSE, including potential enhancements to the code, and other efforts in modeling solvent extraction systems. Efforts have begun to examine the behavior of U(IV) in in TBP-dodecane under variable nitric acid concentrations to aid in running simulations of the CoDCon demo flowsheet using the AMUSE code in order to better bracket the potential behavior of U in the demonstration to generate a product of the desired U/TRU ratio. (C. Pereira)
- **[PNNL]** The level M3 milestone, M3FT-17PN030108048, measurement of training sets, was completed during the reporting period. Training sets for the quantification of Pu and U (in multiple oxidation states) have been completed for both the aqueous and organic phases. A short document summarizing the items included in the training set along with example spectra is currently being prepared. This document will be sent by the WPM to the Federal Project Manager and the NTD to document the final completion of this task. (G. Lumetta)
- **[PNNL]** A preliminary counter-current flow experiment was performed to explore the effects of changing the flowrate of the fresh TBP solvent in the uranium "re-extraction" stages of the CoDCon flowsheet on the amount of uranium in the uranium/plutonium nitrate stream (although only uranium was used in this test). The test was limited to four 2-cm centrifugal contactor stages. The fresh TBP solvent was fed into stage 1, the U-loaded TBP solvent was fed into stage 2, uranium(IV) solution was fed into stage 3, and stage 4 contained a dilute nitric acid scrub. The test conducted will be simulated using the AMUSE code and compared with the experimental results. Adjustments will be made to the AMUSE parameters (e.g., U(IV) distribution ratios) to better match the experimental results to improve the fidelity of the AMUSE simulation of the full flowsheet. (G. Lumetta)
- **[PNNL]** Chemometric model development is underway with preliminary modeling indicating accurate quantification of species of interest such as Pu(III), Pu(IV), and U(IV). Models will be further optimized to allow for robust analysis under complex solution conditions. (G. Lumetta)
- **[PNNL]** Procurement of the on-line spectroscopic monitoring system is proceeding appropriately according to the set timeline. The Raman system has been delivered to PNNL and the UV-vis system has been ordered with an expected delivery date in April. Additional system components such as flow cells, fiber optics, probes, etc. have also been ordered and will be delivered along with the UV-vis system in April. (G. Lumetta)
- [**SNL]** CoDCon Modeling, FT-17SN03010806, The CoDCon process monitoring model has been built in Matlab Simulink. This model will be used to explore plant transients and other off-normal

conditions to more fully test the process control aspects of the CoDCon flowsheet. A draft report has been written and circulated for review. (B. Cipiti)

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]** Hosted the joint Modeling/Simulation Workshop with MRWFD that took place in Phoenix, AZ, Feb. 1-2. Continued to prepare for the March joint Working Group Meeting with MRWFD.

SAFEGUARDS AND SECURITY BY DESIGN - ECHEM

Microfluidic Sampler

- **[ANL]** Began installation of the droplet generator in the actinide glovebox for testing with uranium-bearing salts. Received the droplet generator flow cell system from Argonne shops. The system is being assembled to ensure proper fits. Several of requested changes were not made to the as-built system, so modifications are required to ensure that the equipment will work properly once installed.

Modeling and Simulation for Analysis of Safeguards Performance

- **[ANL]** Development of the AMPYRE code is progressing to allow for sequencing and sizing of individual unit operations. Improvements to the user interface and the code pertaining to head-end operations have been made, which allows for better tracking material early in the process, from dismantling of fuel assemblies through basket loading. This facilitates sequencing of events later in the flowsheet. Changes to the code have also been made to account for material accumulating between unit operations that are not running on the same cycle. This provides flexibility to model, for example, a facility where uranium product processing is run continuously because of the larger rate of uranium product collection whereas the U/TRU product processing or metal waste treatment operation is run periodically, after an appropriate amount of material has been collected. Participated in the joint MPACT-MRWFD Mod/Sim meeting in Phoenix. Presented at the Mod/Sim meeting in Phoenix, AZ.

Electrochemical Sensor

- **[INL]** Experiments were performed to study the potentiometry of LiCl-KCl-xGdCl3 eutectic using a Bi-Gd electrode in the exchanged beta" alumina sensor. The purpose of these experiments is to familiarize the new experimenter with the process and validate the use of a Bi-Gd electrode as the sensing electrode in the actinide sensor before the experiments with uranium.

Voltammetry

- **[ANL]** Evaluation of the performance of the prototype sensor is progressing well. Tests of a system designed for operation in an aqueous system are nearing completion and have provided confirmation of design feasibility. An electrode system fabricated for molten salt operation is undergoing performance testing. No issues have been identified with electrode operation.
- **[INL]** An experimental plan is being prepared to study electrode material compatibility.

Electrochemical Signatures Development

- **[LANL]** Work continued to port moving-objects code from MCNPX to MCNP6. The parallel-execution Message Passing Interface (MPI) coding was successfully implemented for moving objects. In brief, MCNP MPI works by 1) data initialization for the master process, and 2) use of the master

data for subsequent initialization of the slave processes. MCNPX & MCNP5 did the slave initialization by reading data written to the run tape file. MCNP6 initializes the slave processes via direct broadcast from the master process. After reviewing the code, modifications to dyn_msgbcast in setdas. F90 were implemented. Initial tests have been executed for the pyroprocessing SALT, LCC, and HULLS models using up to 512 processors on the Pete Linux cluster. These models contain neutron or gamma sources. Execution time does not scale directly with processor use due to MPI and processor issues, but tremendous net reductions in wall-clock time are apparent. Execution has been done using mesh tallies and the PHL detector tally for gamma. One issue was noted. The HULLS neutron-source model execution gives two lost particles for 107 source histories. Models should not lose particles. For conventional MCNP applications, lost particles are usually symptomatic of user error in the geometry model. For the new moving-objects feature, a code bug could exist. There are many intricate steps in the moving-object simulations involving particle creation, banking, and geometry updates for cells and universes (two MCNP geometry containers). The cause of the lost particles was under investigation at the end of the reporting period. Monte Carlo simulations are very time consuming. MPI enables parallel execution, with significant reductions in elapsed wall-clock time vs simulations executed using a single processor. MPI will thus facilitate enhanced simulation capability, including spectral tallies. These tallies will be studied for their ability to elucidate particular emissions and sources. A report containing a detailed description of the MCNP moving-objects work for MPACT pyroprocessing continues to be written.

ADVANCED INTEGRATION

Advanced Integration (Methods)

- **[LANL]** Developed a coding framework for the Advanced Integration concept to generate Receiver Operating Curves (ROC) for process flow data that comes from tools such as ExtendSim. Process Flow tools can generate operational data as a function of time. For instance, ExtendSim can produce tank level data for the three head-end tanks (Dissolver Product Tank, Feed Inventory Tank, Feed Makeup Tank) for PUREX reprocessing. Given a diversion scenario, the tank levels may change. Using actual tank level data along with predicted tank level data and a threshold for detection provides the information for generating a ROC for that respective tank. The ROC curve shows the Probability of Detection (Pd) for a given diversion scenario as a function of the Probability of a False Alarm (Pfa). Each point on the ROC curve represents a pair (Pd, Pfa) corresponding to a particular decision threshold. The likelihood of a false alarm increases when the threshold difference in the tank level becomes smaller. It becomes harder to confidently detect a diversion if the difference between actual and predicted tank levels is small. The ROC curves will provide a library of detection data given a desired detection goal for each unit operation in the reprocessing plant. Work has also continued on developing the Bayesian sequential change-point models coupled with development of decision rules for data fusion. Results for the change-point models were presented at the recent joint Mod/Sim meeting that was held in Phoenix, Feb. 1-2. For those models, simulation has gotten underway using simulated data output from the ExtendSim model of the Purex nuclear reprocessing facility. The change-point model simulation efforts examine false alarm rates at different levels of posterior change-point probability thresholds and are also quantifying detection probabilities under the different data fusion decision rules.

Advanced Integration (Facility Models)

- **[SNL]** The interfaces between the STAGE code and other codes within the program have been fleshed out. We are working with the other labs to examine passing of data between capabilities. CTH simulations for the spent fuel ratio (SFR) were discussed with shock-physics SMEs . The

models will be run on SNL supercomputing resources. An abstract based on the expected simulation results was submitted to the 58th Annual INMM Meeting.

- **[LLNL]** Completed calculations and sent the results to SNL. Working with SNL to provide data for INMM conference.

MIP Monitor and CoDCon

- **[PNNL]** PNNL and UTK staff evaluated the gathered data. H-Canyon is preparing for another processing in the canyon this quarter. Work at UTK continued on evaluating alignment procedures. Dr. Bruce Pierson, PNNL, has leveraged other models to the raw data gathered for this effort. His analysis are as follows. Acquisition of some of the data gathered at H-Canyon began prior to the cycling of the sampling boxes in the hot sampling aisle. The sampling boxes were cycled for 30 minutes in an effort to get a stable signal from the source. Data acquisition began prior to cycling. These exercises were code named 2018, Charlie, X-ray, Yankee, and Zulu. In each case, process flow conditions were adjusted and the ensuing change in the gamma-ray field generated by changing feed flow conditions was captured using a NaI detector. Figure 1 illustrates the time-varying count rate observed during exercise Charlie and figure 2 is a close-up of the lower energy range.

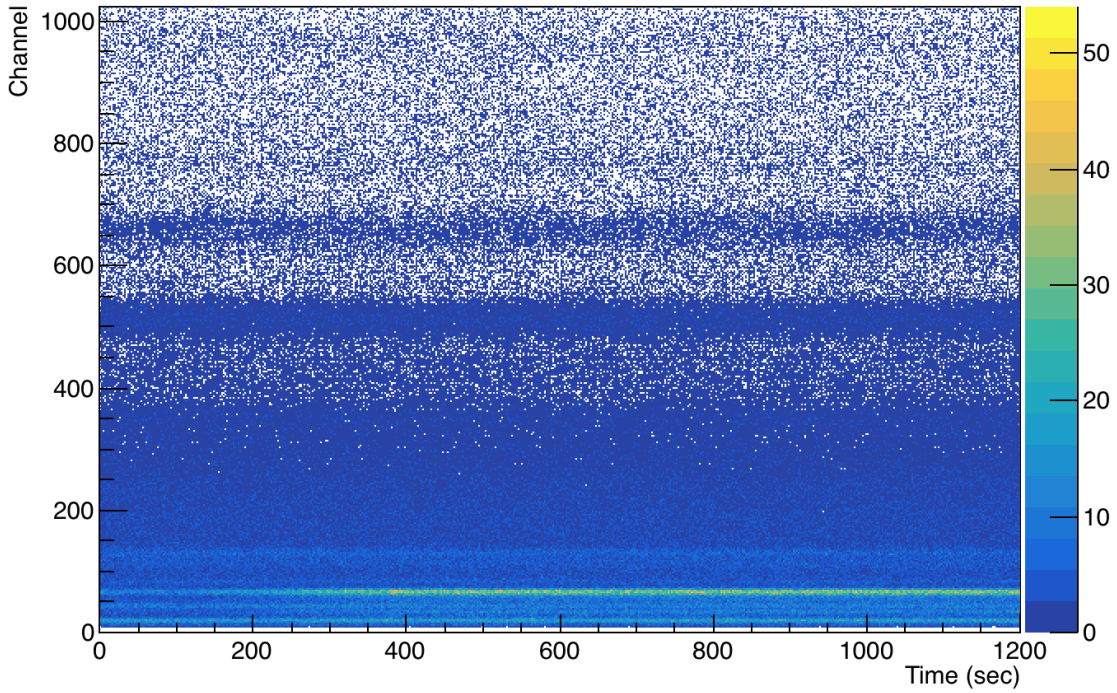


Figure 27. Time-varying count data from exercise Charlie

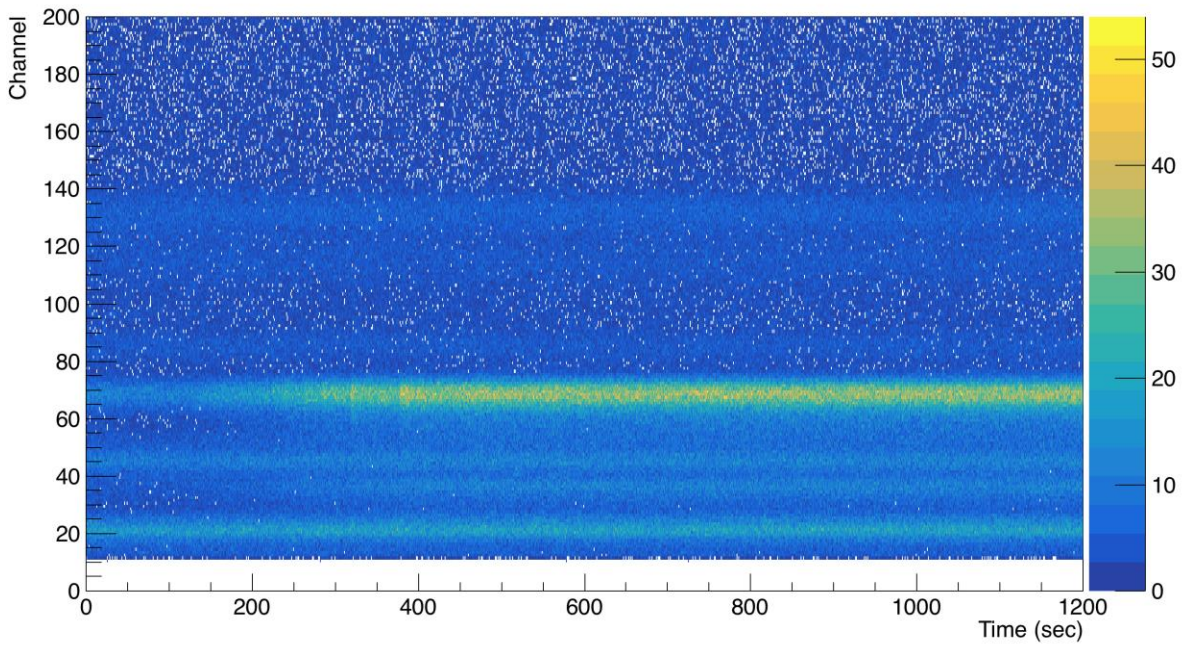


Figure 28. Close up of first 200 channels of exercise Charlie.

From these visuals, the ramp excursion looks to run for a total of 250 seconds before the peak at approximately channel 35 comes into equilibrium. The objective of this analysis was to evaluate the k-means clustering method, applied to the input spectral data to identify and characterize the ramp. K-means clustering is a method that minimizes the Euclidean distance (square-root of sum of squared differences of each coordinate) between a user defined number of locations in space (nodes) and the data points in a space of dimensionality equal to the input data stream[1]. For example, given a collection of points in 3-dimensional space, the k-means method starts with a set of nodes and calculates the distance of said nodes from the data points, then proceeds to adjust the location and discrete point set assigned to each node to minimize the overall distance of the points from the nodes. After minimization, the collection of data points nearest a given node is defined as a unique population separate from the other node locations. There are other clustering algorithms that do not strictly fix the set of initial nodes. Some of these algorithms try and split nodes as the distances increase and merge nodes when they get too close to one another during the minimization process. This is done to find an optimized set of nodes. One such method is the agglomeration method. There are many caveats that impact the performance of clustering algorithms. One caveat, not fully explored, is the impact of different dimensional reduction methods on the input data set and alternative clustering using maximum-likelihood methods. Because k-means is a spatial method, the discrete cluster sets will always be contained within a similarly sized region, that doesn't necessarily mean the same number of points will exist in the region. An alternative approach, the agglomeration method, allows for differing regional sizes as nodes are combined. Agglomeration can have difficulty with homogenous input data and has the potential to label whole input data sets as one cluster, which is not the case for the five exercises. Both the k-means and agglomeration methods were applied to data collected during exercise Charlie. Full spectra, using 5 second binning, were provided as data points to each algorithm. Using full spectra gave an overall dimensionality of 1024, not ideal for clustering, but a simple approach. Fifteen nodes were used for the k-means clustering analysis. Figures 3 plots the clusters as a function of time, and figure 4 presents the sum of all spectra assigned to nodes plotted together.

EXPLORATORY RESEARCH / FIELD TESTS

Microcalorimetry

- **[LANL]** The high-frequency superconducting coaxial cables have been received at LANL and appear to meet specifications. The cryostat system can now begin to be fitted with the microwave readout components in the coming months. Mark Croce and Katrina Koehler traveled to the MIT research reactor to begin irradiation of a Pt-192 sample to create the electron-capture decaying nuclide Pt-193. Microcalorimeter measurements of the Pt-193 will test fundamental limits of energy transport and measurement in microcalorimeter absorbers and will be a main theme of Katrina Koehler's PhD thesis.

High Dose Neutron Detector

- **[LANL]** Testing of the repaired pod using in-house 226Ra source was completed and options for further testing are under discussion. Two identical additional detector modules were procured and are being manufactured by the vendor.

In situ Measurement of Pu Content in U/TRU Ingot

- **[INL]** Using the new lid on the top-loading furnace in the Engineering Development Lab (EDL) argon glovebox, 29 g silver was melted and compared to the previously characterized data using 14 g aluminum. Shown in Figure 3 are the external thermocouple measurements versus the internal thermocouple measurements for the Ag and Al. The correlation of the Al data is very good with the Ag data.

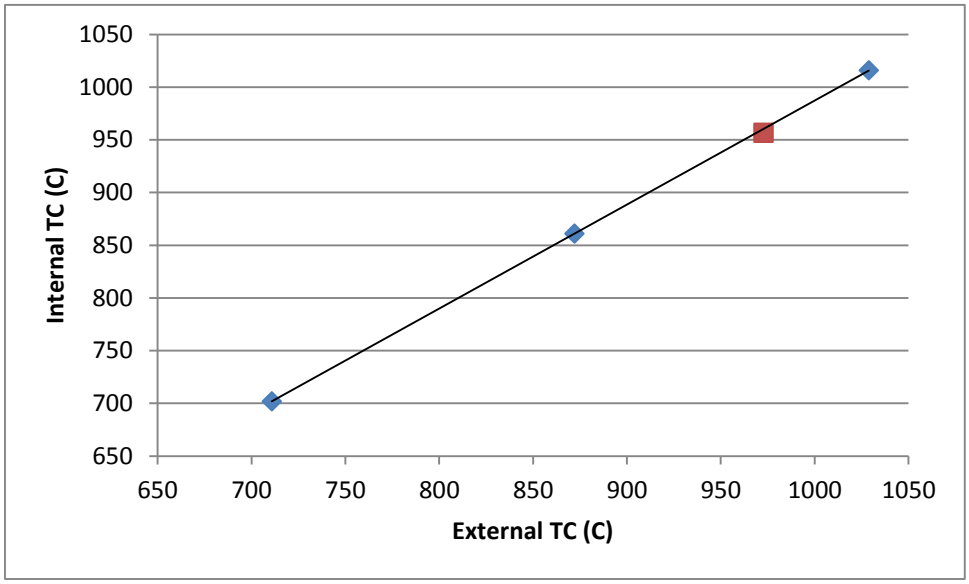


Figure 3. Top-loading furnace characterization with new lid and Al (blue) and Ag (red)

H-Canyon Support

- **[SRNL]** Hosted PNNL researcher, Dave Meier, for a 2 day data collection trip at H Canyon. During this visit training was also updated to allow for Dave to continue working in the H Canyon contamination area in a respirator. Prior to the trip, training was set up and arranged by SRNL staff. One to two more data collection trips will be scheduled for FY17.

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

Fuel Cycle Options Campaign

CAMPAIGN MANAGEMENT

- **[INL, ORNL, ANL]** Completed preparation of presentation materials, and briefed DOE-NE and NRC Managers on MSR technologies and their status, at DOE-HQ, Germantown, February 16, 0217.
- **[INL]** Continued to develop the FCO SharePoint site and develop a standard process to provide access for users at other labs who are foreign nationals.

EQUILIBRIUM SYSTEM PERFORMANCE (ESP)

Equilibrium System Analyses

- **[ANL, BNL, INL]** Under the Vanderbilt University NEUP project NEUP 13-5220, the following three fuel cycle data packages (FCDPs) relating to thorium fuel utilization systems were developed, and consistent with the FCDP development procedure, lab personnel reviewed the FCDPs and provided feedback to the Vanderbilt principal investigator.

– Two stage EG25: PWR (HEU) to HWR (Th/TRU)

– Two stage EG25: PWR(LEU) to HWR (Th/TRU)

– Two stage EG26: HWR(Th/U3) to HTGR (Th/U3)

- **[BNL]** Completed external review of Fuel Cycle Data Package (FCDP) submitted by Vanderbilt University/ORNL: Fuel Cycle Option Number: EG26: MC-C-T/T-UTh-U3-N; Fuel Cycle Option Title: "HWR-Th/U3-MOX to HTGR - Th/U3-C." Results were provide to ANL.
- **[INL]** Completed external review of Fuel Cycle Data Package (FCDP) submitted by Vanderbilt University/ORNL: Fuel Cycle Option Number: EG25: MC-C-T/T-UTh-U3-Y; Fuel Cycle Option Title: "PWR-LEU-Oxide to HWR-Th/TRU-MOX." Results were provide to ANL.
- **[ANL]** Attended the Advanced Reactors Technical Summit IV hosted by the U.S. Nuclear Infrastructure Council (US-NIC) and Argonne National Laboratory. The information provided on advanced reactor concepts was collected for the purpose of comparing any claimed fuel cycle performance data to those developed during the nuclear fuel cycle Evaluation and Screening study. Two new reactor concepts, Elysium (molten chloride fast reactor) and Kairos Power (Fluoride molten salt reactor), were introduced during the meeting.
- **[INL]** Initiated development of annotated outlines for the technology-specific equilibrium analysis report and the impacts of load following report. Both annotated outlines help identify the analyses to be performed and the material to be generated during these activities, while providing the structure for the final reports.
- **[ANL, INL]** Held teleconference calls to develop further the activity on load-following impact on the U.S. electricity market, and started to collect information on the U.S. electricity grid market consisting of 3 regulated and 7 restructured markets. A summary on the U.S. grid market was developed, and electricity generation data by energy sources in 5-minute or 1-hour segments, were collected for the electricity organizations SPP, MISO, PJM, etc.
- **[ANL]** In order to improve quality of the NE-COST website, met with the Argonne graphical/web designers. The proposed website has a substantially "cleaner" and visually appealing appearance, including sliders for the input parameters and pie charts for the output results.

- **[ORNL]** Work is underway on reviewing the fuel cycle concepts assigned to ORNL. Four evaluations have been assigned to ORNL associated primarily with plutonium management options. Reports, papers and open literature information is being reviewed ready to write the evaluations.

Economics and Financial Risk Assessment

- **[ANL]** Reviewed the paper "What Would It Take to Reduce US Greenhouse Gas Emissions 80% by 2050?" by Geoffrey Heal of the Columbia Business School, New York, since it is relevant to the FCO campaign activities on "Regional and Global Impact". It was concluded in the paper that "... more limited use of renewables (less than 50%) together with increased use of nuclear power might be less costly." Parts of the paper's calculations are being repeated with cost numbers for nuclear plants that are more defensible than those used in the paper, based on the work done in the FCO campaign to improve the defensibility of input cost data.
- **[INL]** Work is underway on the time series analysis to update the Cost Basis relevant to uranium and SWU prices, and began testing alternative time series models for the purpose of identifying best fit to the data. Preparing a technical draft to document the problem being addressed, the approach, the data, and the issues of concern.

Maintenance of Fuel Cycle Catalog

- **[SNL]** Two of the six fuel cycle options received from NEUP participants were entered into the fuel cycle options catalog database, verified, and made available on the public fuel cycle options catalog website. The other four are in progress and should be completed in March. Work on moving the website from SharePoint 2010 to SharePoint 2016 has been postponed as Sandia's network administrators have postponed the upgrade because of the transition in leadership at Sandia National Laboratories.

DEVELOPMENT, DEPLOYMENT AND IMPLEMENTATION ISSUES (DDII)

Technology and System Readiness

- **[INL]** Continuing work on the technology and system readiness analysis of the aqueous recycle portion of the fuel cycle for the Materials Recovery and Waste Form Development campaign. Developed initial drafts of the Critical Technology Elements (CTEs) evaluation of the fuel chopping and leaching subsystem for the case study and near-term cases. Developed initial draft of the technology readiness level evaluation for the tritium pretreatment process in the subsystem.

Transition to Alternative Fuel Cycle

- **[INL]** Chaired a meeting of the NEA Expert Group on Advanced Fuel Cycle Scenarios February 6-7 in Paris. Activities included review of analyses in progress for benchmark studies on TRU management and dose rate calculations for irradiated assemblies. The group's benchmark report on scenario uncertainties analysis is complete and undergoing final formatting. Also represented the expert group at a meeting of the Working Party on Scientific Issues of the Fuel Cycle on February 8th, where expert group activities were presented and mandates for all expert groups were reviewed and approved.
- **[ANL]** Began developing the end of April deliverable report that would include results of physics studies under idealized conditions and an understanding of the impacts on transition.
- **[ANL]** For the first scenarios of transition to the most promising advanced fuel cycles, the fast reactors are envisioned to start up on LEU and gradually transition to U/Pu or U/TRU continuous recycle. Therefore, the compositions of those cores from the first to fifth recycling passes were

calculated via REBUS-3 and provided to the fuel cycle modeling analysts in order to model the transition to the EG30 system. Results were similar to those provided last month by INL.

- **[ANL]** In order to evaluate a potential glove-box fabrication of fast reactor driver fuel, the dose rate and decay heat for the SFR driver fuel during pass-by-pass EG30 transition were estimated. The preliminary results show that during the first 5 passes, the SFR driver fuel generates less dose and decay heat than for a typical PWR MOX fuel with 8.2% Pu per heavy metal mass.
- **[INL]** Progress continues on the modeling of the EG-30 transition scenario using the VISION model. This has involved the integration of new flow paths to go along with the ANL-generated LEU startup and transition SFR recipes and the coordinating of driver and blanket recipe transitions. The latter process must be done manually, and requires repeated simulation runs to properly capture the timing of each transition. Once completed, these results may be compared to those generated using the INL-derived LEU startup recipes.
- **[LLNL]** Began relevancy reviews of FY17 CINR IRP proposals.
- **[ORNL]** Modeling of EG30 has continued with a lot of progress being made. An ORION model of EG30 at steady state, using the new assumptions has been completed and compared with the other fuel cycle tools. There is very good agreement between ORION and the other tools. The transition analysis of EG30 transition using recipes provided by ANL is now underway. This requires modeling 5 different batches of fuel in the FBR before it can be assumed to reach equilibrium. The models are now being further refined and any likely errors or assumptions addressed. The next phase will include evaluating EG30 transition using cross sections and with and without decay.

Transition Economics

- **[ANL, INL]** The use of LEU fuel in fast reactors at the start of transition will result in a Pu and even a TRU vector that may enable fabrication in glovebox facilities for all fuel cycle options being considered. This is potentially a very large cost savings and delay the challenge of deploying remote fabrications. This item is being studied in more detail to understand the potential benefits.

Regional and Global Impacts

- **[BNL]** Continued the implementation of model updates with costs for non-nuclear technologies from the 2015 Annual Energy Outlook (consistent with the data in GCAM).
- **[LLNL]** Discussed nuclear energy generation issues with energy storage and grid dynamics researchers at LLNL.
- **[PNNL]** Continued the effort of understanding the long-term deployment of nuclear energy within the context of the broader energy system in the US with emphasis on regional differences in energy and technology costs. Effort for February was minimal due to funding constraints.

For more information on Fuel Cycle Options contact Roald Wigeland (516) 732-4234.

Joint Fuel Cycle Study Activities

JFCS OVERSIGHT

- Research of critical technology aspects to support the Integrated Recycling Test (IRT) continues. Campaign personnel continue to field and test equipment for use in the IRT.
- Eight additional irradiated FFTF MOX fuel rods were successfully declad using installed IRT head-end equipment. In total, thirteen of the 14 planned fuel rods have been declad.
- The first irradiated fuel batch was loaded into a product basket, and processing in the oxide reduction system began in February.
- Installation of the scalability testing glovebox began in February. Connections to utilities and equipment control cabinets are underway.

ELECTROCHEMICAL RECYCLING ACTIVITIES

- Head-End: In February, head-end equipment was used to declad eight irradiated MOX fuel rods. A total of 13 of the 14 planned rods have been declad. Fuel recovery continues to average greater than 98%. Gamma scanning of additional FFTF elements was completed to verify element burnup estimates and to assist with location determination for physical sampling. The first batch of irradiated fuel was loaded into a universal basket for processing in the oxide reduction system.
- Oxide Reduction System: The first batch of irradiated fuel commenced processing in the IRT oxide reduction system in February and was completed in March. Improved designs for several oxide reduction system components were installed and operated prior to operations with irradiated fuel.
- Electrorefiner System: The modified internal hardware for the electrorefiner system was installed in HFEF in February and Phase III equipment qualification continued. Heat up tests and loading of eutectic salt were completed. Loading of uranium trichloride and electrorefining of depleted uranium metal is expected to occur in March.
- Remote Distillation Systems: A second scoping experiment with salt-coated depleted uranium dendrites inside a beryllium oxide crucible was completed in one of the HFEF distillation systems with positive results. A management self-assessment to prepare for operations with irradiated fuel was initiated in February and scheduled for completion in March. The distillation system is expected to be used to process the first MOX batch from the oxide reduction system in March. Method development for cadmium and salt distillation process continued in the prototype distillation apparatus at the Engineering Development Laboratory.
- Waste Form Development: Waste form samples transferred from KAERI collaborators continued testing to determine durability and release rates at PNNL and ANL. Engineering drawings for existing equipment to be used in IRT waste form demonstrations are being reviewed by INL export control.

JFCS FUELS

- Fuels – IRT: In February, the IRT casting and sampling equipment was moved from the main table to the extension table to allow head-end processing to continue at HFEF window 10M. Additional tests with gravity casting operations are planned for the March/April timeframe.
- Fuels – Critical Gap: An issue in the casting laboratory glovebox has delayed some critical gap activities. Fuel cladding chemical interaction (FCCI) work using TiN as a diffusion barrier continued, producing diffusion couples of TiN-coated iron against neodymium. Experiments conducted for 24 hours at 500° and 700°C suggest good barrier performance, with negligible neodymium diffusion into

the iron through the TiN. Another diffusion couple experiment was performed using KAERI-provided chromium-coated iron and HT9 against U-20Pu-10Zr-2RE. The diffusion couple was heated to 750°C for 24 hours and samples are being prepared for microstructural analysis.

- Navigation of the process to acquire used fuel bears significant schedule and programmatic risk to the JFCS.

For more information on Joint Fuel Cycle Studies Activities contact Mike Goff (208) 526-1999 or Ken Marsden (208) 533-7864.

Program Assessment & Coordination

PROGRAM MANAGEMENT

- Working on action items from January meeting.
- Completed the NTD conference call on 14 February 2017.
- Completed ALD conference call
- Working on finalization of documents process.
- Completed 10 BCPs to address the funding adjustments directed in the February AFP.

QUALITY SUPPORT

- **[ANL]** Worked on scoping for surveillance. Attended teleconferences.
- **[BNL]** Participated in bi-weekly conference call and started planning for the survey/audit to be completed by June 15, 2017.
- **[INL]** Nothing new to report.
- **[LANL]** Participated in bi-weekly conference calls. Continued work on Revision 3 of the QAPP interface document.
- **[LBNL]** Nothing reported
- **[LLNL]** Nothing reported.
- **[ORNL]** Continued planning and scoping of March 2017 QA audit of select ORNL work packages.
- **[PNNL]** The PNNL QA POC will be conducting training to the FCT QA Interface document regarding the addition of Quality Level 4 (QL-4). In addition, the QA POC will begin scoping activities in preparation for completion of the QA Level IV milestone (completion of an audit) planned for April 28, 2017.
- **[SNL]** Nothing reported.
- **[SRNL]** SRNL continue to participate in biweekly conference call, answer emails, and working on completing the Interface Document revision. SRNL also began preparation for the Surveillance due May 31, 2017.

COMMUNICATIONS

- Preparation for nuclear programs, fuel cycle, and GAIN discussions at upcoming conferences in Washington D.C. and Boston.

INFORMATION MANAGEMENT

- A revised NTRD report template was created and distributed to NTDs and WPMs via email on February 20, 2017.
- FY17 FCT Document Management System (DMS) milestone numbers have been replaced with NTRD DMS numbers in PICS-NE. If a milestone has been submitted, then the assigned FCT DMS number has not changed.
- System patches where completed in February.

- DMS system activity-based activities continue.

REACTOR DIGITIZATION

- The reactor large and small rotating plugs are being modeled. Details on the operating equipment above the core are also being added. Additional detail on the plugs is being found.

For more information on Program Assessment and Coordination contact Bonnie Hong (208) 526-0629.

AFCI-HQ Program Support

UNIVERSITY PROGRAMS

Site: University Research Alliance (URA), Canyon, Texas, and the following universities: University of Michigan, Massachusetts Institute of Technology, University of Texas at Austin, Vanderbilt University, University of Utah, Georgia Institute of Technology, University of Pennsylvania, North Carolina State University, University of California at Santa Barbara, University of Tennessee, Florida State University, Colorado School of Mines, Utah State University, Washington State University, and Rensselaer Polytechnic Institute.

Universities engaged in Nuclear Technology research via URA programs since 2001:

Boise State University
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 PROGRAM

Summary Report

- University Research Alliance continued to send out the program announcement for the 2017 Innovations in Nuclear Technology R&D Awards competition and accept and process applications from students. The program was announced on January 23.
- 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 2017 is midnight Sunday March 19.
- 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

    All submitted publications from eligible students at all universities are eligible to compete for these awards. Awards in the Open Competition are $3,000 for first place awards and $2,500 for second place awards. The intent is to provide first- and second-place awards for well-qualified publications 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 2015 Science and Engineering R&D Expenditures
    - This competition is for students at universities which have lower research outlays. 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.