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NUCLEAR TECHNOLOGY RESEARCH AND DEVELOPMENT TECHNICAL MONTHLY JANUARY FY17

ADVANCED FUELS CAMPAIGN

CAMPAIGN MANAGEMENT AND INTEGRATION

- **[ANL]** A reactor and fuels cross fertilization meeting was held at ANL on Jan. 17 – 18, 2017 to share the overview and accomplishment of advanced reactor and discuss the integration R&D topics, including fast test reactor and licensing activities. (T. K. Kim)

ADVANCED LWR FUELS

LWR Computational Analysis

Metrics Development for ATF

- **[INL]** Minor comments were received on the full-length journal article on MELCOR modification work from Nuclear Engineering and Design: Merrill, B.J., Bragg-Sitton, S.M., and Humrickhouse, P.J., "Modification of MELCOR for Severe Accident Analysis of Candidate Accident Tolerant Cladding Materials," submitted November 2016. This manuscript summarizes work previously reported in milestone reports such that it will be more accessible to the research community. Modifications will be completed in early February. (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 is underway. These models will be used to provide the input data for the analysis of a reactivity initiated accident (RIA) at HZP with the TRACE systems code to complement the analyses that have been performed to-date at full power. (A. Cuadra, M. Todosow)
- **[ORNL]** Recent work on the simulation of FeCrAl cladding has focused on expanding ongoing UO2 mechanics models and determining cladding mechanical limitations. This includes efforts to simulate cladding failure during normal and transient conditions by mechanisms such as PCMI during normal operation and ballooning and bursting during high temperature transient scenarios. (B. Wirth)
- **[ORNL]** As reported previously, work is currently being performed to validate the fuel creep model implemented in BISON. As part of this work, smeared and discrete cracking models are being analyzed in comparison with the ESCORE fuel relocation model [1]. This is performed in order to identify and address deficiencies in fuel behavioral models, which may have an effect on cladding materials that do not behave similarly to Zircaloy cladding. Not only is this effort important for simulating iron-chrome-aluminum alloys, but other accident tolerant cladding concepts as well.
- **[ORNL]** In order to simulate the ballooning and subsequent bursting of the cladding, conditions from cladding burst tests are compared with results from these experiments. This work follows a similar

approach to Pastore et al. [2] and is compared against burst tests from Massey et al. [3]. Figure 1 shows an illustration of the azimuthal creep predicted by a 3D BISON simulation during a LOCA test. Because cladding fracture is not actually simulated, burst criteria must be determined. Ongoing work targeting LOCA behavior of FeCrAl alloys involves identifying a cladding failure criteria. (B. Wirth)

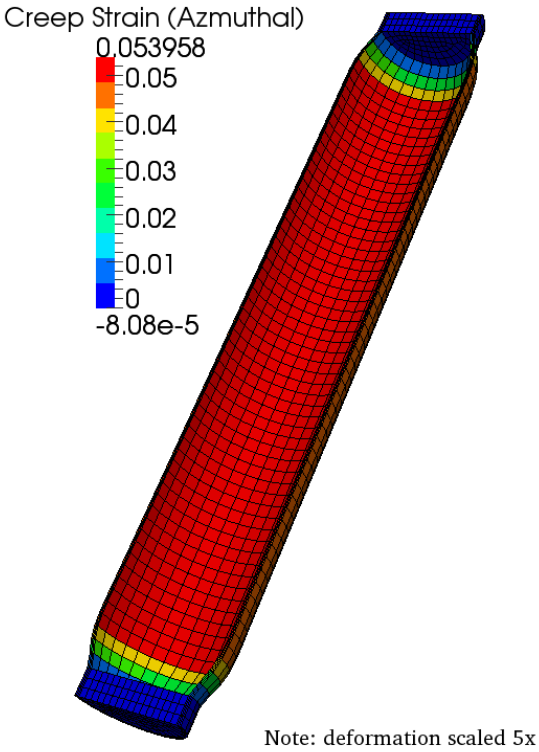


Figure 1. Illustration of the azimuthal creep strain in a cladding tube during a LOCA test. Note that the uniform deformation is due to a constant temperature axially across the tube.

[1] Rashid, Y., Dunham, R., Montgomery, R., Fuel analysis and licensing code: FALCON MOD01. EPRI Report 1011308, 2004.
[2] Pastore, G. et al., Reactor Fuel Performance Meeting - Top Fuel 2015, At Zurich, Switzerland
[3] Massey, C. et al., Cladding burst behavior of Fe-based alloys under LOCA, JNM, V. 470, March 2016, P. 128-138

LWR Fuels

- ***[LANL]*** The level two milestone: M2FT-17LA020201039, "Draft U_3Si_2 Fuel Property Handbook," was completed. This report summarizes the known physical properties of the U_3Si_2, an LWR fuel presently under investigation by both AFC researchers and Westinghouse as a means to enable accident tolerant cladding options through an increased uranium density and improve fuel performance through reduced thermal gradients provided by high thermal conductivity. Data is critically assessed and compiled in order to provide a central and reviewed compendium for researchers both within AFC as well as working under other DOE-NE programs. Attention is also given to datasets that are incomplete or missing to provide guidance for future research efforts on U_3Si_2. (J. White)

- **[LANL]** The level three milestone: M3FT-17LA020201036, "Shipment of Ceramic Fuel Samples to ORNL for Advanced Characterization," was completed. Uranium mononitride and uranium diboride samples fabricated at LANL were transferred to ORNL for hot isostatic pressing (HIP) and spark plasma sintering (SPS) experiments to increase the density of those materials for property measurements to improve upon the models for high uranium density composite ATF concepts. In addition, ORNL possesses a range of electron microscopy capabilities, which will be applied to the aforementioned materials as well as uranium silicide compounds, specifically U_3Si_2. Use of high resolution electron microscopy techniques to characterize the surface chemistry and grain boundary structure of these candidate fuel materials will provide insight into the factors that govern processing and feedstock behaviors. This data, in conjunction with conventional processing optimization work ongoing at LANL, will aid development of methods for commercial fabrication of these nuclear fuels. Sample were received by ORNL on January 20th, 2017, (J. White)
- ***[ORNL]*** *Approximately* **200** mg of UN microspheres were produced with B. The product was NaCl structure UN with a lattice parameter of 0.48991 nm corresponding to the composition UC0.11N0.89. No second phases were detected with XRD. The theoretical density was ~82%. This work shows UN microspheres can be produced with B additives. (J.McMurray)
- **[ORNL]** HIP processing to increase the density of UN microspheres from 85-90% TD to above 95% TD has been demonstrated and a recipe has been established. Critical to the success is the design of the HIP crucible due to the extreme sensitivity of UN to oxygen impurities. (J.McMurray)
- **[LANL]** A proof of principle non-contact measurement of Xenon gas pressure in a steel tube was published in a paper by Tremsin et al. The measurement was made by recording the absorption of neutron resonances in a neutron beam transmitted through a steel tube (~12mm diameter) containing Urania pellets that was pressurized with natural Xe to ~110 ± 3 psi. The pressure inferred from two Xe resonances was 107 ± 14 psi and 109 ± 22psi. The measurements are possible because the depth of the absorption resonances recorded in a transmitted spectrum are controlled by the density of gas atoms in the transmitted beam. The left hand image in Figure 2 below shows the difference in beam path at different locations across the rod. Across the diameter, at the middle of the tube, there is the largest effective "thickness" of Xe gas. This results in a resonance absorption that exhibits almost zero transmission (central image). The absorption spectrum shown in the right image was recorded closer to the edge and demonstrates reduced absorption. (The Mo and Co resonances in the figures result from alloying elements in the steel tube). The gas pressure is inferred from multi-parameter fits of the effective thickness of all the elements contributing to the transmitted spectrum. Further measurements are planned to establish the lowest gas pressure that can be reconstructed and what are the isotopic and geometric constraints. (A. Losko, S. Vogel)
  (see http://scitation.aip.org/content/aip/journal/adva/7/1/10.1063/1.4975632
  DOI: 10.1063/1.4975632

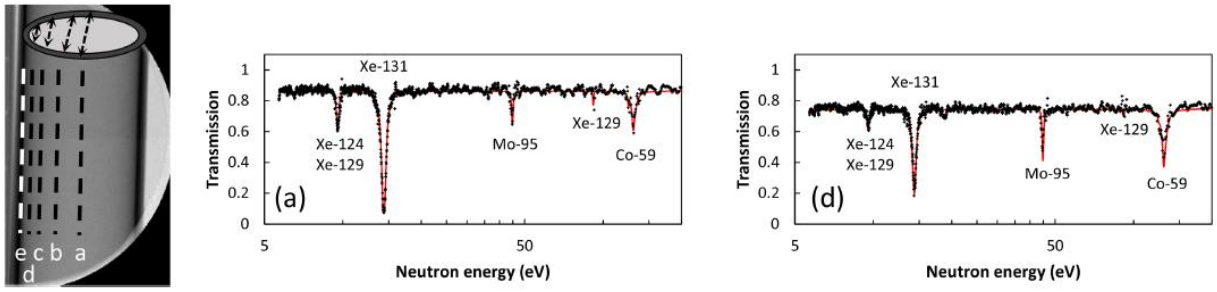


Figure 2. (Left) schematic of rod with different transmission lengths depending on location, (center) transmitted beam spectrum across diameter and (right) transmitted beam spectrum across at a location closer to the outside diameter.

LWR Core Materials

Thin Walled Tube Development

- **[INL]** Sample set 36 was bonded using the pressure resistance weld (PRW) system and will be used for hydraulic rupture testing of the PRW bond (Figure 3). These samples were bonded using the same joining conditions as sample sets 34 & 35. After joining a post-weld heat treatment (PWHT) was applied for these four samples. (PWHT: 700°C, for 2hrs & furnace cool). (J. Gan)

Sample 36-1
Joining Conditions
Time: 2 cycles
Current: 12.74 kA
Energy: 1,156 J
Force: 1100 lbs_f

Sample 36-2
Joining Conditions
Time: 2 cycles
Current: 12.89 kA
Energy: 1,149 J
Force: 1100 lbs_f

Sample 36-3
Joining Conditions
Time: 2 cycles
Current: 12.64 kA
Energy: 1,150 J
Force: 1100 lbs_f

Sample 36-4

Joining Conditions
Time: 2 cycles
Current: 13.06 kA
Energy: 1,147 J
Force: 1100 lbs_f

Figure 3. Sample set 36.

- **[INL]** Set 36 samples were handed off for CT analysis prior to rupture testing analysis. Results should be received in early February. (J. Gan)
- **[INL]** Sample 35-1 & 35-2 were analyzed via x-ray CT to visualize the weld (Figure 4). Sample set 35 was bonded via the PRW process and no PWHT was used. These samples will be used to evaluate the tensile properties of the PRW bonded without a PWHT. With CT analysis completed, these samples will be tensile tested in February. (J. Gan)

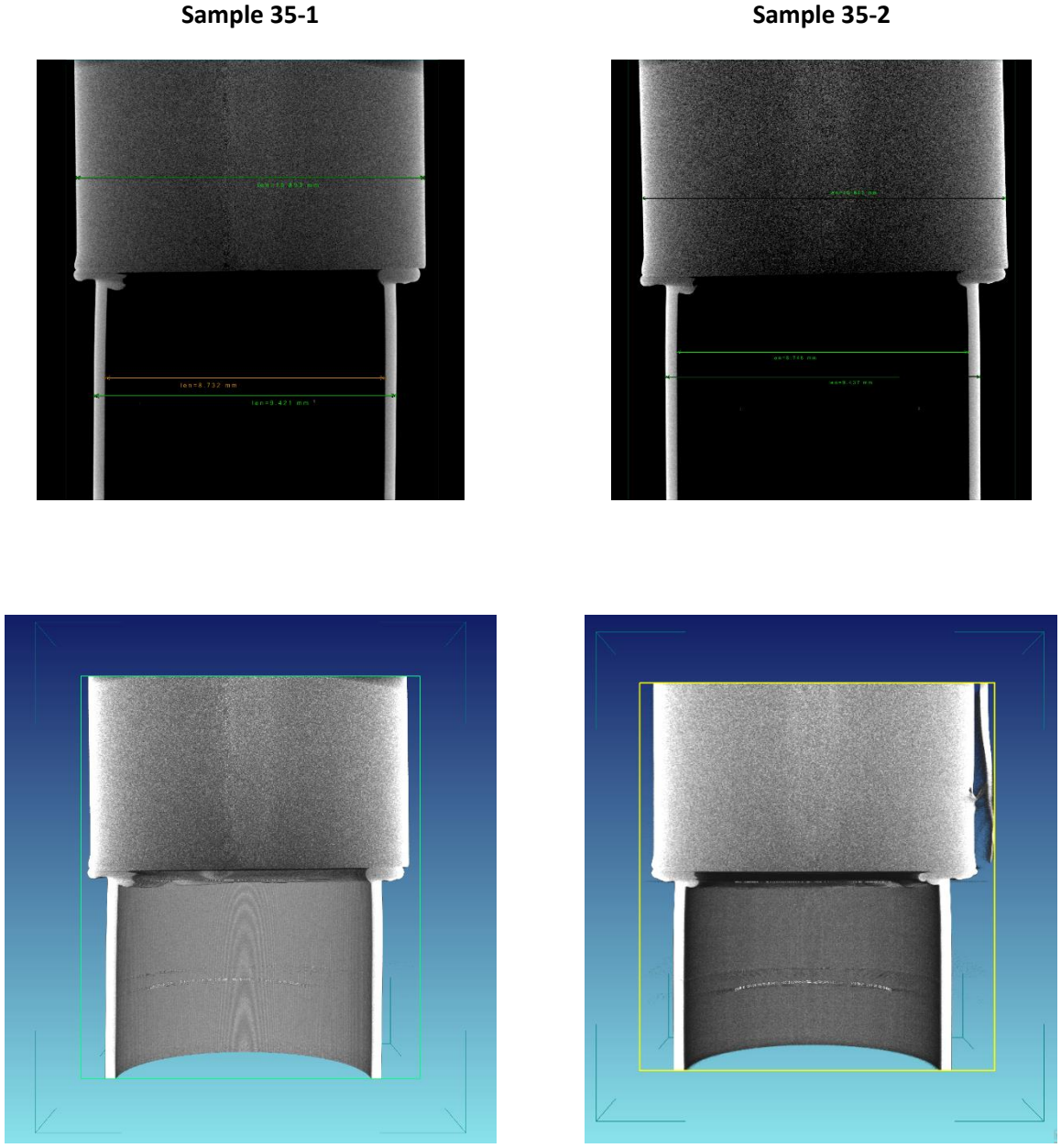


Figure 4. Sample 35-1 and 35-2.

- **[INL]** The bleed holes on LBW endplugs for tensile testing at elevated has been modified. Last month's update showed bleed holes placed into the LBW endplugs in a direction aligned with the

endplug axis. Instead, bleed holes were placed in a direction perpendicular to the endplug axis in order to facilitate better functionality at keeping the internal volume equalized to that of the ambient atmosphere, as well as to promote better fit-up within the Gleeble system where the high temperature tensile testing will occur (Figure 5). (J. Gan)

Figure 5. New bleed hole location.

- **[INL]** The out-of-tolerance endplugs for the PRW process to be used for rupture analysis have been received back from the machine shop. The length of the endplugs has been corrected to within tolerance for the bonding process. (J. Gan)

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. Three out of six billets of HIPed C26M alloy were extruded. They were sectioned into 20.5-inch-length bars, straightened at 300C, and then annealed at 900C for 30 minutes, to make master bars to be gun-drilled and tube-drawn. Microstructure characterization indicated that the bars consisted of equi-axed grain structure with ~80-100 um grain size, which should be good as an initial microstructure of the drawing process. The target final tube size was changed into 0.404" OD x 0.016" WT with the expected total length of 80-90ft. Discussion of the modified draw process schedule was initiated with Century Tubes, Inc. (Y. Yamamoto)

- **[ORNL]** Effects of Nb addition on recrystallized grain sizes and texture formation in FeCrAl alloys were investigated by using annealed C36N3 (Fe-13Cr-6Al-0.7Nb base, in wt.%). The warm-rolled C36N3 plate at 300 °C with total ~80% thickness reduction was annealed in a temperature range from 800 to 1100°C. Recrystallization nuclei were observed after annealing at or above 900 °C. Fine elongated recrystallized grains formed in the temperature range from 900 to 1000 °C which was due to the pinning effect of Laves phase precipitates formed along the rolling direction. Figure 6(a) and Figure 6(b) show the orientation distribution function (ODF) maps comparing the recrystallization texture of the Mo containing alloy (C36M2, Fe-13Cr-6Al-2Mo base, in wt.%) and C36N3. As previously reported (in December, 2016), recrystallized C36M2 showed a strong γ texture fiber (i.e., <111>//normal direction [ND], corresponding to the peak in the map). However, as shown in Figure 6(b), recrystallized grains in C36N3 did not have a strong γ fiber, but only a weak <100>//ND fiber with orientations ranging from {110}<100> to {100}<100> and the Goss component (i.e., {110}<100>), indicating that the deformation resistance of the annealed C36N2 during tube fabrication could be smaller than C36M3. Figure 6(c) shows the recrystallized grain sizes of the annealed C36M2 and C36N3 plotted as a function of annealing time. The results indicated that

C36M2 exhibited grain coarsening at 800°C, whereas C36N3 alloy showed an improved grain size stability even at 950 °C. These results suggest the potential advantage of the Nb addition on the tube fabrication process. (Z. Sun, Y. Yamamoto)

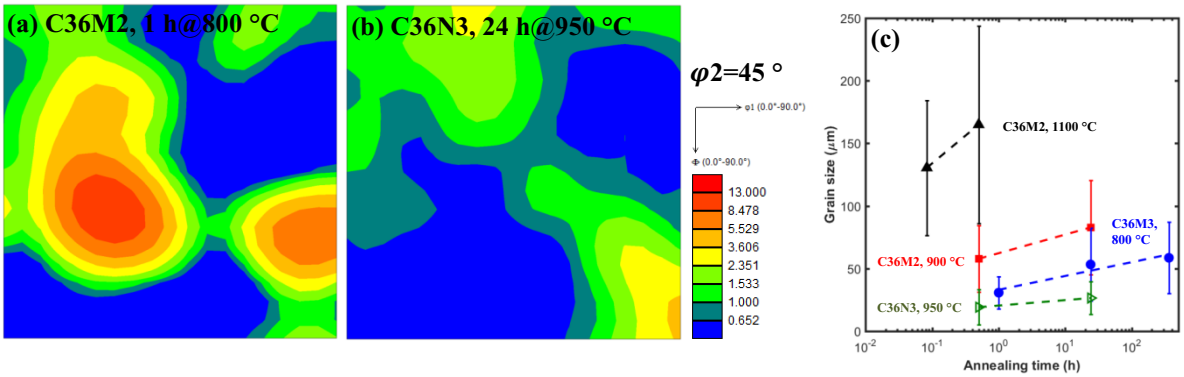


Figure 6. Orientation distribution function maps of (a) C36M2 after annealing for 1h at 800°C, (b) C36N3 after annealing for 24h at 950°C; and (c) Grain coarsening kinetics of C36M2 and C36N3 at 800-1100°C.

- **[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). Samples were cut from the ion irradiated coupons to investigate the change in microstructure using TEM. (S. Maloy)
- **[LANL]** The contract with the University of Rochester for tritium diffusion testing is being reworked at LANL to emphasize that a student will be doing the work at the University of Rochester as part of an educational project. The samples and SS tubing for deuterium diffusion testing are still being cleaned in the machine shop by Rick Hudson. (S. Maloy)
- **[LANL]** Tensile testing of Gen I and Gen II FeCrAl tubing (B126Y, C06M2 and C36M3) was completed at 25, 300 and 600C. Fracture surfaces were analyzed and data was compiled into a report to meet a level 3 milestone. Results show the highest strength for the C36M3 alloy with lower ductility. C06M2 exhibits slightly lower strength but a strong improvement in ductility at all temperatures. Both Gen II alloys (C06M2 and C36M3) showed improved strength over Kanthal AF at 600C. (S. Maloy)
- **[LANL]** Nanohardness testing was completed on welds of Generation II FeCrAl alloys. The data shows that strength was maintained in the weld with some slight softening from the large grain size in the fusion zone. Data compared well with tensile testing performed on these welds at ORNL. This data was compiled into a report to meet a level 3 milestone. (S. Maloy)
- **[ORNL]** Two 250mm long Fe-10Cr-6Al-0.3Zr + Y2O3 rods were shipped to Dr. Kan Sakamoto from the Nippon Nuclear Fuel Development Company for tube fabrication. The tensile properties of these two rods extruded at 1100ºC were lower than the tensile properties of similar Fe-10Cr-6Al-0.3Zr + Y2O3 alloys extruded at lower temperatures, but were still significantly higher than the tensile properties of high strength FeCrAl alloys. The elevated extrusion temperature was chosen to lower the alloy hardness values to ~300HV and thus facilitate tube production. (S.Dryepondt)
- **[ORNL]** Ex situ and in situ small angle neutron scattering (SANS) experiments will be performed on ODS FeCrAl(Zr) powder. Small quantities of ball milled FeCral(Zr) powders have therefore been annealed at 900 or 1000ºC in sealed ampoule quartz for a duration varying from 15min to 2h. These powders will be analyzed using SANS to assess the size and density of the nano precipitates after

annealing. In-situ SANS measurements will then be conducted on FeCrAl(Zr) powders annealed at 900 and 1000ºC. (S.Dryepondt)

- **[LANL]** A M3 milestone (M3FT-17LA020202131) was completed with the submission of a report on January 31st, summarizing fabrication and characterization of molybdenum (Mo) tubing by fluidized bed chemical vapor deposition (FBCVD) and CVD methods. This report shows the fine microstructure that can be obtained using this innovative growth technique for producing Mo tubing. (M. Beaux, I. Usov)
- **[ORNL]** Polished cross-sections of SiC/SiC composites were observed before and after irradiation to investigate microstructural stability. As shown in Figure 7 below, both Hi-Nicalon Type S and Tyranno SA3 fibers reinforced CVI SiC/SiC composites showed stable microstructures; no notable microstructural change, such as fiber/matrix debonding and obvious change in carbon interphase thickness, was observed following irradiation at ~300°C to 11.8dpa. This result is consistent with retention of the flexural strengths following irradiation. By contrast, significant cracking was observed in the irradiated Ultra SCS fibers of the CVI SiC/SiC composite. This irradiation-induced cracking is expected to be caused by differential swelling between the carbon fiber core and CVD SiC fiber region. This cracking explains the significant strength degradation of this composite by irradiation. In summary, we obtained microstructural data which reasonably explains the flexural behavior of the irradiated composites. Note that we have completed most of the PIE on SiC composites irradiated up to 11.8dpa. The results from this task were presented at the conference shown below. (T.Koyanagi, Y. Katoh)
  - Anisotropic swelling of SiC composites during neutron irradiation, Yutai Katoh; Takaaki Koyanagi; Lance L. Snead; Ken Yueh, 41st International Conference and Expo on Advanced Ceramics and Composites, January 22-27, Daytona Beach, Florida
  - Mechanical properties of SiC composites neutron irradiated under LWR relevant temperature and dose conditions, Takaaki Koyanagi; Yutai Katoh, 41st International Conference and Expo on Advanced Ceramics and Composites, January 22-27, Daytona Beach, Florida

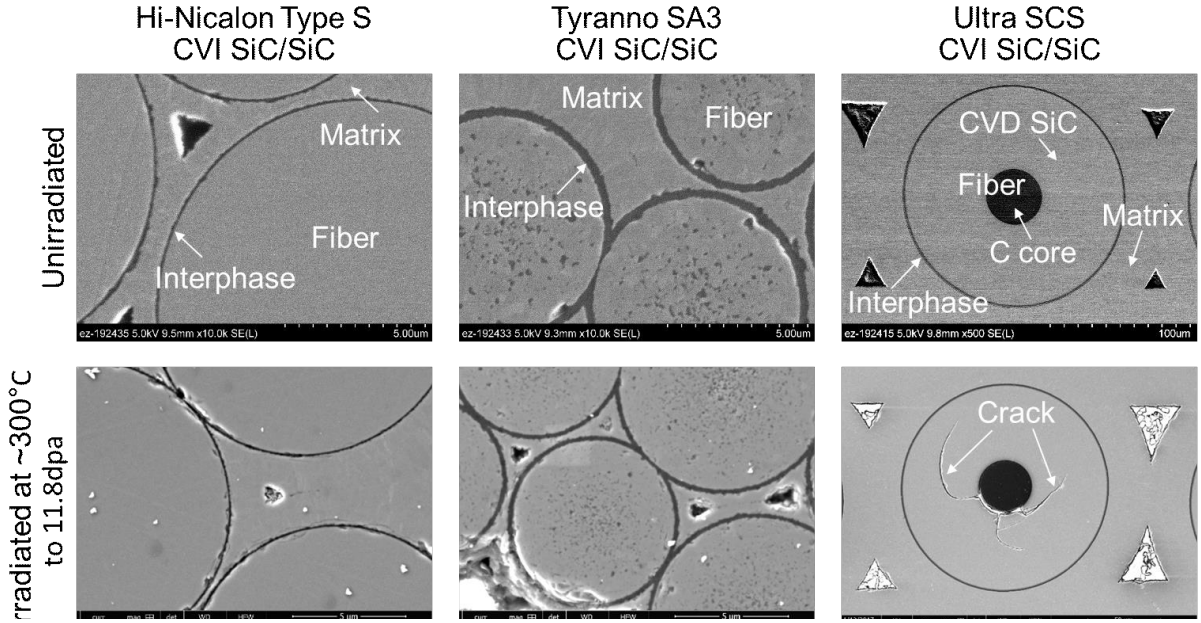


Figure 7. Hi-Nicalon Type S and Tyranno SA3 fibers reinforced CVI SiC/SiC composites, Ultra SCS fibers of CVI SiC/SiC composite.

- **[ORNL]** Two irradiation experiments were conducted on coatings developed with industrial vendors and guided by ORNL. These are respectively HYCO (HYbrid COating) "Dry" (June-Oct 2016) and HYCO "Wet" (Jan- 2017). The HYCO Dry experiment was conducted to determine the irradiation response of the coating-substrate interface of eight coatings and four bond coats on SiC. The SiC surfaces included current cladding materials with minimal overcoat, machined rectangular coupons of SiCf-SiC materials and CVD SiC coupons. Neutron irradiation was conducted to a neutron fluence of 4.8 x 1024 n/m2, or a SiC displacement damage of ~0.5 dpa. (T.Koyanagi, Y. Katoh)
- **[ORNL]** The linear swelling of SiC is expected to be about 0.5%; the response of the coating to this dimensional change has now been evaluated by preliminary optical micrographs from capsule deconstruction. As hoped, all PVD coatings had no visible damage, although there were significant discolorations. PVD coating technologies have been commercially established for well over two decades. The key feature of the processing is the ability to control tensile stresses by defective microstructures. A crucial question is whether the tensile stresses are still mitigated after evolution under neutron irradiation at higher doses; the dislocation density, amorphous content and implantation regions are likely to undergo substantial change. (T.Koyanagi, Y. Katoh)
- **[ORNL]** Both vacuum plasma spray Zircaloy-2 (VPS Zr) and electrochemical coatings were at early stages of development and were included in HYCO Dry. VPS Zr coatings had <25 wt% retained Zr and as a result, the irradiation yielded information about the radiation response of zirconium silicide and carbide phases, which can be considered the "bond coat" in these coating systems. After irradiation, edge cracks were observed on coupons, but no visible damage was observed on coupon faces and cladding sections. In the electrochemical coatings, it appeared that the successful deposition of electrolytic chromium still resulted in the expansion of the microcracks instrinic to the Cr layer after irradiation. This appeared to be supported by the absence of damage on the surface of the nickel bond coats on SiC submitted as reference/control samples. (T.Koyanagi, Y. Katoh)
- **[ORNL]** Development VPS Zr and electrochemical coatings have continued; in VPS, preserving the Zircaloy-2 content is the priority, while in electrochemical coatings, the removal of microcracks by alloying appeared to be successful, and the electrochemical Ni-Cr has proceeded toward a NiCr (nichrome) concept. The latter was able to be included in the HYCO Wet irradiation, which began this month. The above results will be presented at PACRIM9 and the upcoming FCRD report, and depending on activity, further results may be included. If so, the focus of technical content will be on the microstructural evolution of these coatings under neutron irradiation. These will be supported by autoclave testing of the coatings that were successful in HYCO Dry. (C.Ang, Y.Katoh)
- **[ORNL]** The circumferentially non-uniform boundary condition was implemented in the 3D full-length pellet-cladding model through a simple method (Figure 8). The accuracy and robustness of this method will be tested in forthcoming work. (G.Singh, Y.Katoh)

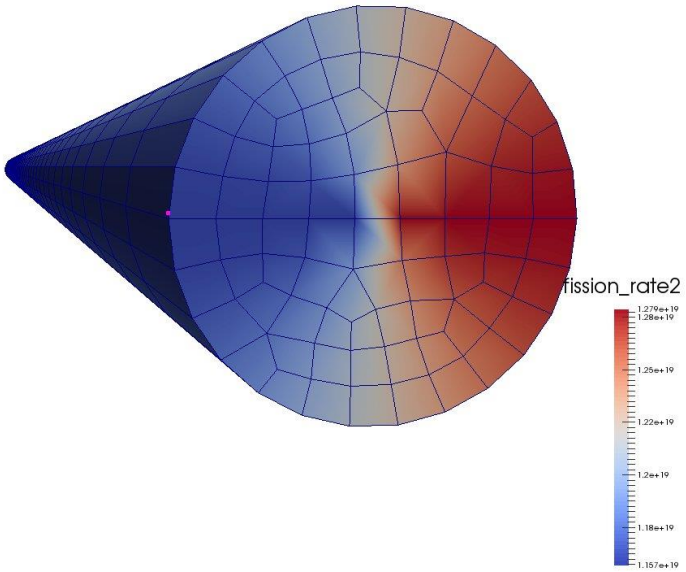


Figure 8. Non-uniform fission rate in the fuel pellets.

- **[ORNL]** Interlaboratory round robin testing of SiC/SiC composite tubes was completed by all the labs. The data was analyzed and initial results were presented at the ASTM meeting in Daytona. The Digital Image Correlation system (DIC) is being set up. The DIC system will be employed for assessing the accuracy of the measured strains during the hoop tensile testing of SiC/SiC tubes. (G.Singh, Y.Katoh)
- **[ORNL]** Steam testing of "B" tubing (B136Y) was initiated at different ramp rates, holds and final temperatures to simulate the planned QUENCH tests at KIT in Germany. The first 4 scenario tests were completed at temperatures up to 1500°C. Several experiments will be repeated with APMT tubing from GE. (B. Pint)
- **[LANL]** Initial TEM characterization of Fe-Cr-Al samples aged to simulate the evolution of native oxides at cladding operating temperatures is ongoing. Structural analysis of APMT samples aged in air for periods of 100-500 hours is complete. Characterization of the 100-hour samples has revealed that alpha-alumina is present at a thickness of roughly 40 nm following aging at 600C. Crystalline alumina is capable of acting as a tritium barrier, while the thin (~10 nm) amorphous surface oxide formed at lower temperatures is not. This observation represents the lowest temperature that crystalline alumina has been observed during oxidation of a Fe-Cr-Al alloy of the composition relevant to ATF LWR cladding. However, continued aging of times up through 500 hours does not result in appreciable coarsening even in this high oxygen environment. Analysis of APMT aged at 500 hours showed that the alumina layer had only grown an addition 5 nm from the thickness obtained after 100 hours. The probability of a ~50 nm Al2O3 layer mitigating tritium diffusion is not known and requires further study. Chemical characterization using TEM-EDS is ongoing to determine the composition of the surface region of these aged samples in preparation for publication. (N. Li)

LWR Irradiation Testing & PIE Techniques

- **[INL]** Design of a disassembly device for ATF-2 was initiated. Engagement with the irradiation vehicle designers at this stage should facilitate disassembly at the start of PIE. (J. Harp)

- **[INL]** Design drawings were revised to include a Hf shroud on tiers 1, 2, and 4 to lower the fuel centerline temperature for UO2 fuel rods in those tiers of the test train. The drawings have been sent to the analysts for review and comment. A technical checker has been assigned to review the drawings but he cannot start until mid-February due to other commitments. Design changes were incorporated into revisions of the Conceptual Design Reports for the Industry Partners. The revised reports are being used along with the revised drawings to perform re-analysis of the new configuration. (K. Barrett)
- **[INL]** The Sensor Qualification Test (SQT) safety analysis is being revised to address heat rates of additional cladding materials to be incorporated in the test train. SiC and coated Zr-4 will be included in the test train as well as the originally analyzed APMT cladding tubes. After detailed discussions with the Industry Partner teams, it was determined that inclusion of these cladding materials would provide pertinent information on chemical compatibility, swelling, and corrosion rates prior to the ATF-2 fueled test. ATR experiment engineering also requested that INL neutronics analysis include analysis assuming a maximum 3000 ppm boron (double the desired maximum concentration) to ensure inadvertent errors to chemistry adds in the loop would not cause an Experiment Safety Analysis (ESA) violation and/or reactor SCRAM. (K. Barrett)
- **[INL]** The ATR chemistry conditioning test of the water loop 2A using Pressurized Water Reactor (PWR) chemistry shows positive results for establishing and maintaining the chemistry within the ranges specified by the Industry Partners (see Figure 9 and Figure 10 below). The only exception is the H2 content which tends to fall outside the range at the low end after a couple days. We are working with Westinghouse and Halden engineers to improve our H2 add process to maintain this level within desired range. We will continue to monitor the loop chemistry through duration of the 160B-1 cycle and following 161A-1 PALM cycle prior to inserting the SQT test train cycle 162A-1. (K. Barrett)

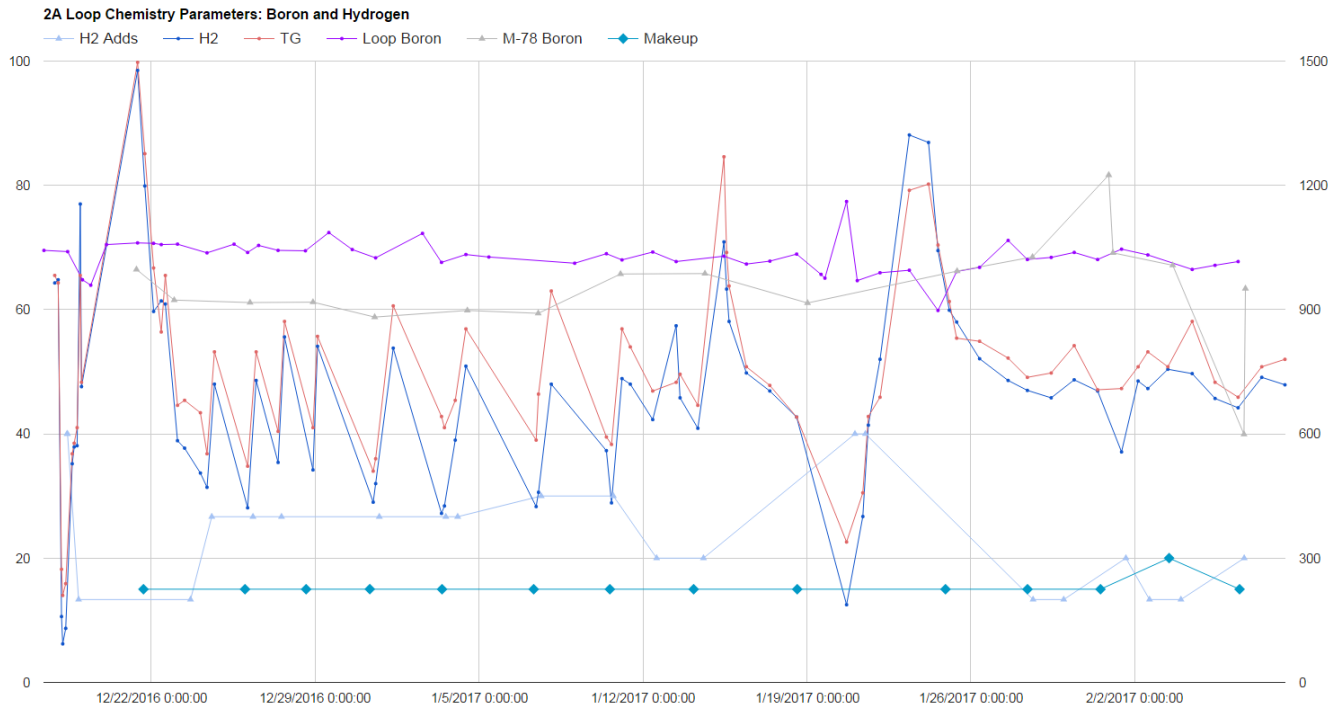


Figure 9. ATR Water Loop 2A chemistry conditioning results for boron and hydrogen concentrations.

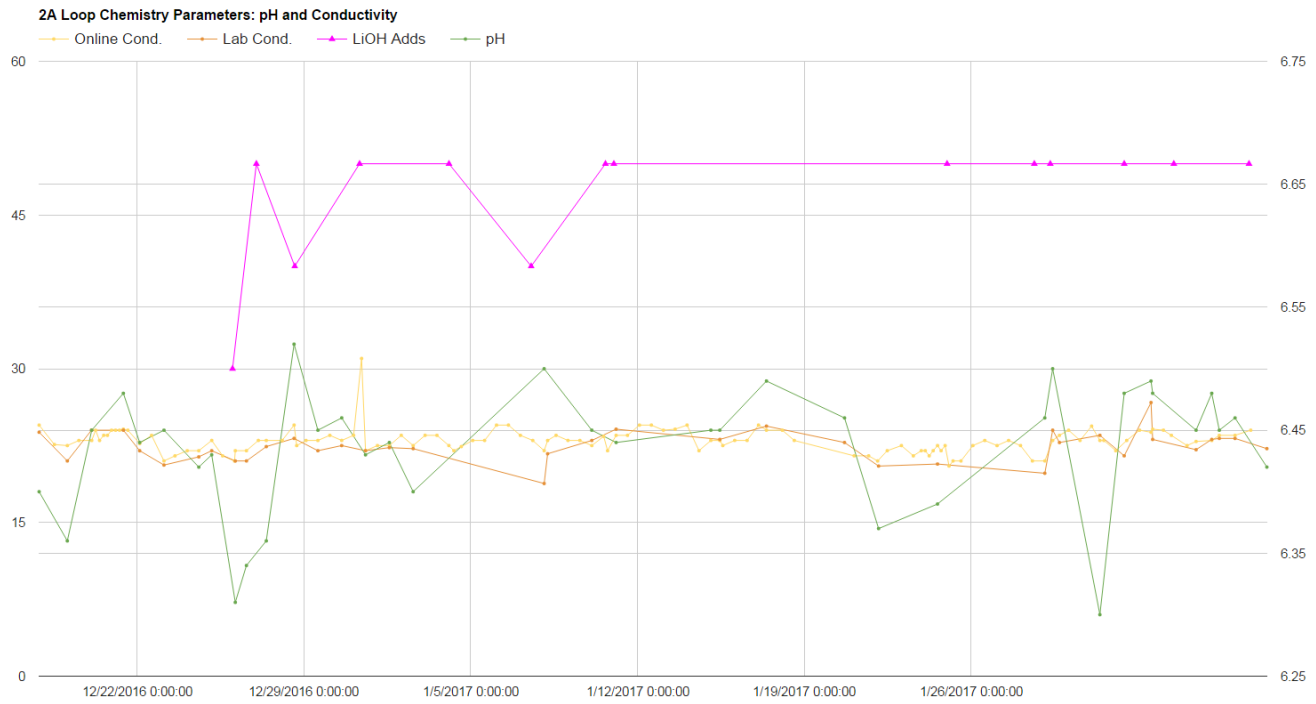


Figure 10. ATR Water Loop 2A chemistry conditioning results for conductivity and pH.

- **[INL]** A Cooperative Research and Development Agreement (CRADA) between INL and Westinghouse has been developed and reviewed by Westinghouse to support a collaborative effort to test a variety of sensors in a mock-up Sensor Qualification Test (SQT) in an autoclave loop at the Westinghouse Churchill, PA facility. The CRADA is undergoing INL and Westinghouse management review then will be sent to DOE for final review/approval. The autoclave test is scheduled to begin late March – mid-April 2017. Results will support SQT irradiation testing in ATR cycle 162A. (K. Barrett)
- **[INL]** A welding and brazing process plan has been issued and welding/brazing development work is making significant progress ahead of schedule in preparation for the autoclave test train assembly in Feb-March. (K. Barrett)
- **[INL]** Test train components for the autoclave and SQ tests are being fabricated at an accelerated rate to ensure that we do not miss the experiment scheduled tests. (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 starting cycle 161A 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]** Halden IFE Facility staff returned from furlough in January, resuming design of BWR/PWR test rigs. The internal audit and final review of the designs are expected in February with analysis and

safety assessment s to begin upon approval. Discussions of Halden reactor ATF experiment testing are held monthly with IFE. (E. Mai, K. Barrett)

- **[INL]** Scanning transmission micrograph (STEM) of the phases observed in Pu-Am-Zr alloy were completed (Figure 11). Features with different contrast correspond to different phases formed in the alloy. This is a first known attempt to conduct TEM analysis of such alloys. Selective area diffraction patterns were collected from each formed phase, which will be used to identify all phases formed in the alloy. This data will be used to improve our knowledge of these complex systems, provide input to phase diagrams, and ongoing modeling efforts. The importance of this work to the FCRD program is that the project investigates early stages of microstructural evolution in metallic fuels, radiation enhanced diffusion and fuel cladding chemical interaction, constituent redistribution, and thermophysical property evolution. The results from this experiment will be utilized to help validate computational models that are currently being developed at INL. (C. Papesch)

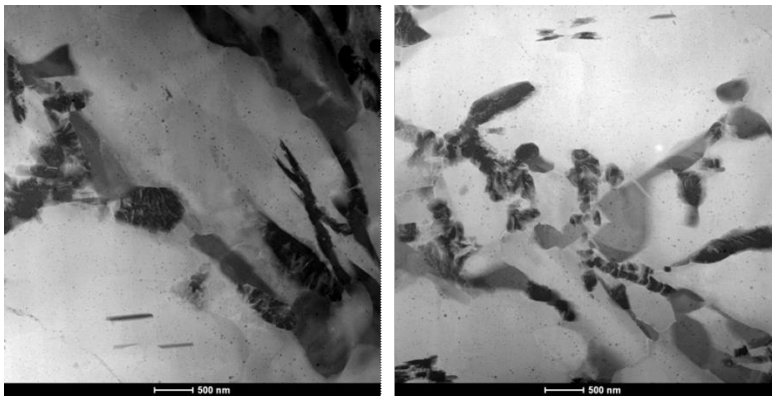


Figure 11. Scanning transmission micrograph (STEM) of the phases observed in Pu-Am-Zr alloy.

- **[INL]** Analysis has begun on X-ray diffraction patterns of legacy metallic fuel from the AFC1 experiments (C. Papesch)
- **[INL]** Analysis was begun on U-Zr-Sn and U-Zr-Sn-Ln, with an image of U-Zr-Sn shown in Figure 12. At least three distinct crystal phases are present. This is expected due to the large number of intermetallics available between tin and Zr or U, not including possible ternary phases. Differential scanning calorimetry is underway, with the first scan shown in Figure 13 below, and samples for X-ray diffraction have been cut. They will be polished and sent for XRD in February. Samples are in a furnace undergoing annealing. These will be analyzed in March. (C. Papesch)

Figure 12. SEM image of U-Ar-Sn alloy.

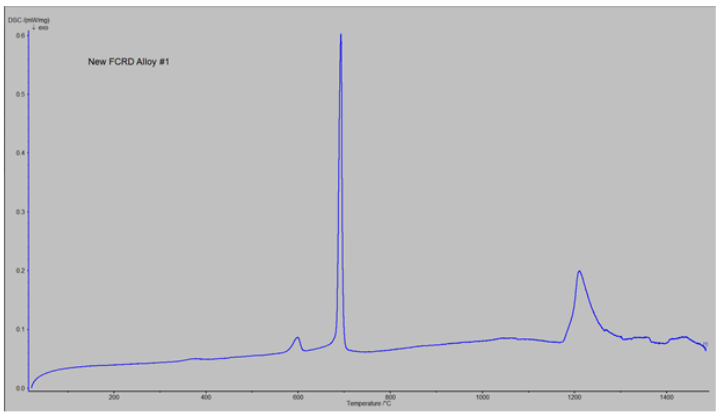


Figure 13. DSC curve of U-Zr-Sn.

- **[INL]** The first draft of an engineering design for the LFA that will be installed into the thermal properties test cell at IMCL was received. The design has been forwarded to INL engineering and it currently being reviewed. (C. Papesch)

LWR Transient Testing

- **[INL]** The Multi-SERTTA Handling Mockup and core interface hardware fabrication has been completed and delivered to TREAT. This full-size equivalent-weight handling mockup will allow TREAT to rehearse the complete handling evolution (core, cask, storage holes, etc.) to ensure proper fit, confirm functionality of fixtures/tools, and gain operational experience. (J. Schulthess)
- **[INL]** The Multi-SERTTA prototype fabrication is well underway. Notably, the majority of the bulk machining for main pressure vessel components has been completed (Figure 14). Completion of the prototype will enable system testing and design qualification later in FY17. Prototype testing will be performed as described in PLN-5271. This document was finalized in December, 2016 and met a program milestone. (J. Schulthess)

Figure 14. Bulk machining for main pressure vessel components.

- **[INL]** Preparatory work on the Test Plan revision has reached a point where the revision may begin. Input from the FOA partners is the final data that we are awaiting. Completion of the Test Plan will enable commencement of the ATF-3 conceptual design. (D. Dempsey)
- **[INL]** An integrated lifecycle schedule is under development. This schedule will provide good insight into future Irradiation Testing impacts from current/potential delays in the related TREAT experiment development activities.(D. Dempsey)
- **[ORNL]** Demonstration experiments were performed on current zirconium-based alloy cladding tube behavior under Pellet Cladding Mechanical Interaction (PCMI) conditions that mimic the strain rates observed in the low temperature phase of a reactivity initiated accident (RIA). Based on the data obtained by the tests, a draft journal paper related to the AFC pulse controlled modified burst test device is prepared and undergoing internal review at ORNL. The paper addresses the design details and mechanical pulse control. These shakedown tests have been performed on uniformly hydrided ZIRLOTM samples (see Figure 15). (M. N. Cinbiz, N. R. Brown (PSU))

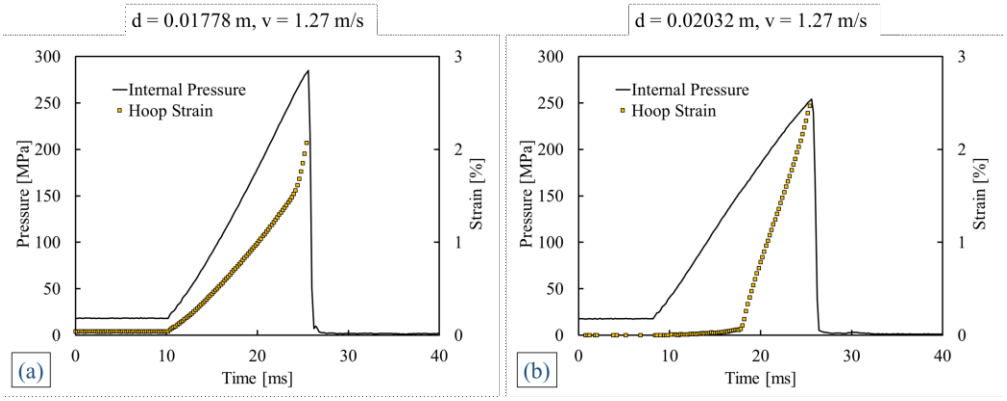


Figure 15. Evolution of (a) the internal pressure of driver tube and (b) hoop strain on the sample surface during modified-burst test to simulate RIA event for pre-hydrided ZIRLOTM samples (~1500 wt. ppm).

- **[ORNL]** Preliminary modified-burst test results of unirradiated silicon carbide fiber/silicon carbide matrix composite (SiC-SiC) were presented at the *International Conference and Expo on Advanced Ceramics and Composites 2017*. The talk highlighted preliminary results of mechanical testing of SiCf -SiCm composites the importance of dynamic testing at a variety of strain rates, to appropriately mimic PCMI conditions. (M. N. Cinbiz, N. R. Brown (PSU))

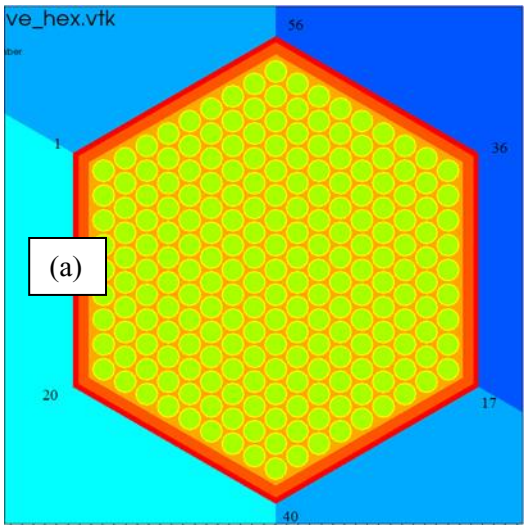
ADVANCED REACTOR FUELS

AR Computational Analysis

- **[INL]** Radial power profile in unshrouded MAMOX fuel was calculated and its impact on fuel microstructure is being evaluated. Recent literature indicates that void migration in MAMOX begins at 1400-1500C. Based on this threshold, formation of central void formation at 350W/cm unshrouded fuel cannot be ruled out. (P. Medvedev)
- **[LANL]** The fully working coupled zirconium redistribution example problem was submitted into the BISON repository. Papers highlighting the capabilities of BISON to test advanced fuel designs were submitted to FR17 and ANS summer meetings. The initial MCM formal calibration was performed for the zirconium distribution kernel. (C. Unal)

AR Fuels Development

- **[ANL]** In order to know the temperature and flux distributions in Americium Bearing Blanket (AmBB) fuel, a full ASTRID core was modeled using the high fidelity NEAMS systems. The AmBB assembly was modeled pin-by-pin and other assemblies were modeled homogeneously (Figure 16). The flux distribution in the AmBB is provided in Figure 17 below, which is close to the results obtained from legacy tools. Additional detailed temperature distribution is under way. (G. Aliberti)



(b)

Figure 16. AmBB assembly model for PROTEUS calculation.

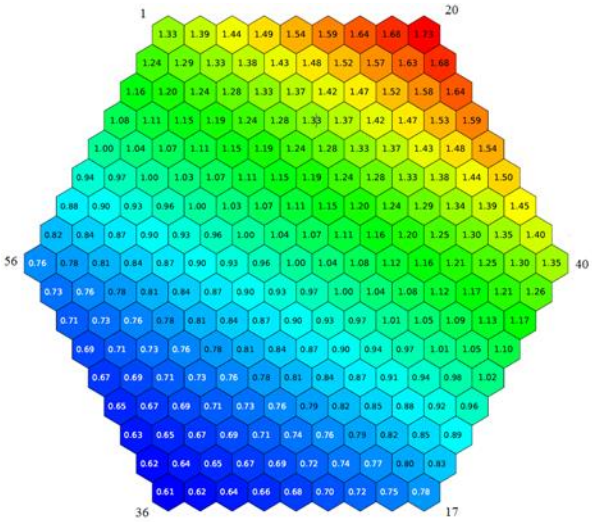


Figure 17. Normalized flux distribution in AmBB assembly.

- **[INL]** It was discovered when the americium metal produced via the distillation process was retrieved for sampling that it was oxidizing rapidly. Figure 18 below demonstrates how the material changed in a relatively short period of time.

Figure 18. (a) Am metal just after distillation and (b) after storage in a Swagelok in the AFCI glovebox for approximately one month.

The oxidation was occurring even though the material was in a sealed metal (Swagelok) container within the AFCI glovebox which is an inert atmosphere glovebox in which oxygen levels are normally held below 10ppm. Immediate action was necessary to protect the material from further oxidation. The action that was decided upon was to consolidate the flakes of metal into larger balls of material to decrease the surface area, thus decreasing the oxidation potential and hopefully preserving the metal inside the ball. This was achieved via arc melting. New hearths were designed for the process that would allow the light flakes of material to be placed inside a well to keep them from bouncing out when the arc was struck (Figure 19). The hearths were also designed to be split just in case the material stuck to the hearth, although that did not happen.

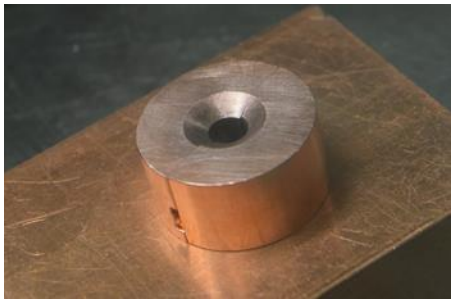


Figure 19. Hearth designed for americium metal consolidation.

Surrogate experiments were performed in FASB using iron flakes. Once it was determined that the process worked it was moved into the AFCI glovebox in FMF to begin consolidating the americium metal. The process was successful and all of the material is currently being consolidated into small BB sized balls of approximately 0.5g each (Figure 20). (L. Squires)

Figure 20. Ball of consolidated americium metal.

- **[INL]** Work under Advanced Fuel Fabrication Development is focused on three major areas; fuel cladding chemical interaction (FCCI) barrier coating/liners development, stoichiometry control system and oxide transmutation fuel development, and improved small scale casting furnace design. In the area of FCCI barriers, work has progressed to incorporate zirconium foils on the fuel slugs. Optical analysis of previously cast pin with 0.001" Zr foil (Figure 21) continued to show that this foil thickness does not properly contain the uranium alloy. Optical analysis of previously cast pin with 0.005" Zr foil showed that the thicker foil better contained the fuel. Near the top of the pin, the fuel can still be observed in the middle of the foil overlap but does not continue down the length of the pin as observed with thinner foils. (L Sudderth)

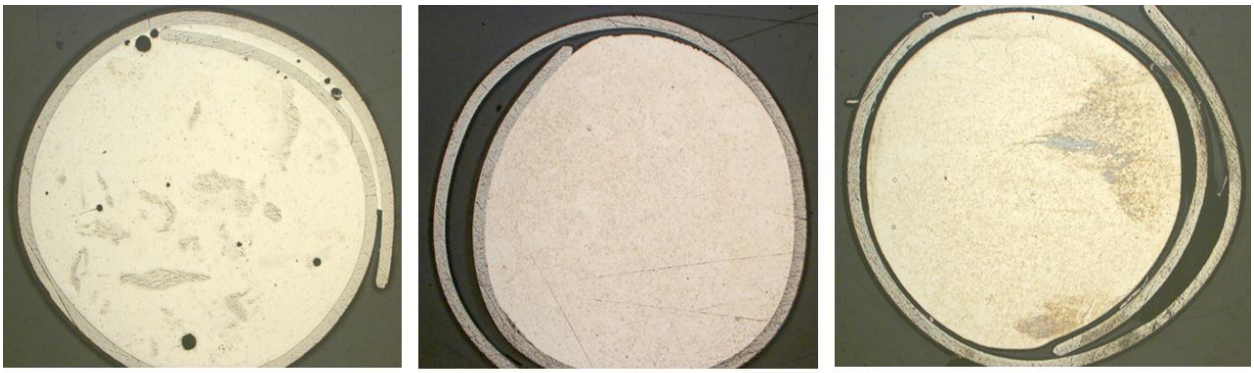


Figure 21. Optical analysis of previously cast pin with 0.005" Zr foil.

- **[INL]** A casting trial using 0.0005" Zr foil confirmed that the nature of the thin foils poses challenges when casting via arc-melting. There were large deformations observed in the as-cast pin, and optical images of pin cross-sections showed degradation of the foil throughout the length of the pin (Figure 22). (L. Sudderth)

Figure 22. Degradation of the foil throughout the length of the pin.

- **[INL]** Engineering on the SCS panel and equipment procurement is progressing. The gas mass flow controller will be upgraded to use a digital control system. The new controller has been ordered and is scheduled to arrive in February. In addition to the mass flow controller upgrade, oxygen monitoring will also be added to the system both before entering the furnace and exiting. The oxygen monitors have been received and have been examined to determine if any additional engineering requirements have been added. (Seongtae Kwon)
- **[INL]** The conceptual design of an improved casting furnace has been initiated with initial requirements established. During previous AFC irradiation test fabrication campaigns arc casting has been used to cast metallic fuel. Although this system has worked for a number of years, results have been variable, sometimes adding significant time to the fabrication schedule. The goal of the new casting furnace will be to incorporate a controlled induction casting technique while maintaining the ability to arc melt in the glovebox while keeping any additional glovebox equipment footprint to a minimum. The current concept will make use of the arc melter base and stand, as well as electrical cables. This concept will maintain functionality of the arc caster, with some re-configurations, and minimized any additional footprint. (R. Fielding)
- **[INL]** According to the relevant phase diagrams, tin could be a promising fuel additive to control fuel-cladding chemical interaction (FCCI). To explore this potential, two alloys were fabricated, U-10Zr-4.25Sn, and U-10Zr-4.25Sn-5Ln (where Ln = 53Nd-25Ce-16Pr-6La). Pins were cast of each alloy, and cut for analysis (scanning electron microscopy, X-ray diffraction, differential scanning calorimetry, and annealing studies). Initial characterization results of these alloys is reported in the fuel characterization section of the monthly report. To further explore the potential for tin to prevent FCCI, alloys were cast of SnNd and SnCe. A slice from each pin will be polished and assembled into

a diffusion couple with iron. By themselves, Nd and Ce react very strongly with iron at 650°C, thus this is a good initial test for the ability of tin to prevent FCCI. (Michael Benson)

AR Core Materials

- **[LANL]** In collaboration with the IRP on High Dose Ion irradiation testing, shear punch testing was completed on all irradiated samples to compare with ion irradiated samples. These samples will be shipped to UC Berkeley to cut TEM foils using their Focused Ion Beam. (T. Saleh)
- **[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 for microstructural observation, and it was found that a moderate density of microvoids where found dispersed throughout the sample. The voids were found to contain TaMnN particles. 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]** In support of milestone "M3FT-17PN02030204 - Issue Report on Accelerator-to-Accelerator Differences in Radiation Response (FY16)," discussions continued with LANL on a collaboration to look at the effect of different accelerators on the microstructure of ion irradiated materials. LANL and PNNL each have 14YWT that was irradiated in a different accelerator, but the alloy processing history and examination methods of the alloys are slightly different. Because of this, it is likely that the material at PNNL will be ion irradiated in another accelerator to provide the comparison. The most likely accelerator to use will be the LANL accelerator. (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]** The creep data of MA957 and 14YWT (SM10 heat) was obtained from the terminated long-term creep tests and analyzed. The MA957 specimen that was tested at 825ºC and 70MPa was determined to have survived the creep test for 61,351 hours before the test was stopped. The 14YWT specimen that was tested at 800ºC and 100MPa lasted 20,327 hours before the test was stopped. The secondary creep rate measured for the MA957 specimen was very low (6.2×10^{-12} s^{-1}) while that measured for the 14YWT specimen was also very low (2.6×10^{-11} s^{-1}). The creep strain for each alloy near the end of the tests was ~0.25-28%. The highlight of these results is that both the MA957 and 14YWT have remarkable creep properties at elevated temperatures and stresses, which is desirable for fast reactor applications as fuel clad. (D. Hoelzer)
- **[ORNL]** Two manuscripts covering the microstructure and creep properties of MA957 tested in six conditions starting in 2003 are in progress. Additional microstructural characterization of the crept specimens including the preparation of specimens from the recent MA957 specimen that was exposed to 825ºC and 70 MPa for 61,351 hours are being conducted for TEM and atom probe analysis. The microstructural characterization results will provide valuable insight into the stability of the Y-Ti-O nanoclusters in MA957 after long-term exposure at high temperatures and loads. The publication of the creep results will add to the very limited data that exists in the literature on advanced ODS ferritic alloys. (D. Hoelzer)
- **[PNNL]** The research paper titled, “A Comparative Assessment of the Fracture Toughness Behavior of Ferritic-Martensitic Steels and Nanostructured Ferritic Alloys,” will be published on February 28, 2017 in the *Journal of Nuclear Materials*. This article was written based on the milestone report (M3FT-16PN020302061) and aimed to elucidate the differences and similarities in the temperature

and strength dependences of fracture toughness in a variety of Fe-Cr alloys to provide an assessment of their high-temperature structural performance. The article was evaluated highly for a large scale integration of useful fracture toughness and strength data for the Fe-Cr alloys. (T.S. Byun)

- **[PNNL]** Efforts continued on processing development of toughened HT9 steels, including thermo-calc simulation on the thermodynamic behavior of HT9 steels during tempering and machining tensile specimens for the first group of thermomechanically treated materials. In the HT9 steels, the new isothermal tempering consisting of pre-tempering (300 – 600 °C) and tempering at 750 °C is the key process to produce desirable hardening particles, and therefore the simulation focuses on the precipitation behavior, in particular, during the lower temperature pre-tempering. (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. Two MA956 tubes are ready for pilgering on the pilger mill at Sandvik. A 14YWT thick wall tube extrusion has been completed and is staged for pilgering as indicated below. Time on the Sandvik pilger mill is scheduled for mid-February. Although it is not known if both the MA956 and 14YWT thick-wall tubes can be fit into the schedule, current planning is to attempt to pilger both. (R. Omberg)
- **[PNNL]** The 14YWT extrusion has been cleaned up and is staged for pilgering at Sandvik along with the two MA956 thick-wall tubes. A photo of the completed 14YWT extrusion after cleanup is shown in Figure 23 below. (R. Omberg)

Figure 23. Thick-wall tube extrusion of 14YWT staged for pilgering.

AR Irradiation Testing & PIE Techniques

- **[INL]** Physics analysis for the shipment to a PIE facility of experiments AFC-3C-(capsules 1-5), AFC-3D-(capsules 1-5) and AFC-4B-(capsules 3 and 4), has been completed. This analysis provides input to the Nuclear Safety, Transportation, Safeguards, and receiving facility personnel so that they may begin their required shipment analyses. (D. Dempsey)
- **[INL]** PIE was initiated on a historically irradiated fuel pin from the X-501 assembly. This pin, X-501 G591, is a full length Minor Actinides (MA) bearing metallic fuel pin irradiated in EBR-II up to 7 at% bu. This pin was retrieved from storage in HFEF and was visually examined this month in HFEF. Neutron radiography will be performed next month using the HFEF NRAD reactor. X501-G591 is one of the kind pin fabricated by injection casting and irradiated in EBR-II that contains few wt% of MA. Full PIE will be of incredible value in comparison with others MA bearing metallic fuel such as AFC-1 and FUTURIX-FTA. (J. Harp)

CAPABILITY DEVELOPMENT

Fuels

- **[INL]** Work is continuing on an instrument to measure the thickness of thin transducer films used with the TCM. This effort is approximately 40% complete. We are also working with vendors on optical fiber feed through for the glove box. One quote has been received. A schematic of the lasers setup has been forward to the MFC Laser Safety Officer and the IMCL facility manager for their approval. A possible issue has been identified concerning the compatibility of the stage motors with the argon atmosphere in the glove box. We are working with vendors to determine the stage motor compatibility. (D. Hurley)

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

MATERIAL RECOVERY AND WASTE FORMS DEVELOPMENT

REFERENCE TECHNOLOGIES AND ALTERNATIVES

- **[ORNL]** The design of the NO_2 voloxidizer system stand has been completed (see Figure 24) and a request for quotes was submitted to different vendors. As mentioned previously, cold testing of the unit revealed minor equipment modifications were needed for the mixing blade. The redesigned blade is being fabricated and delivery is expected by mid-February. The potential to run the off-gas lines out of the hot cell to allow for easier trap replacement is being reviewed and planned as it required separate HEPA filtration and safety class equipment. (B. Jubin)

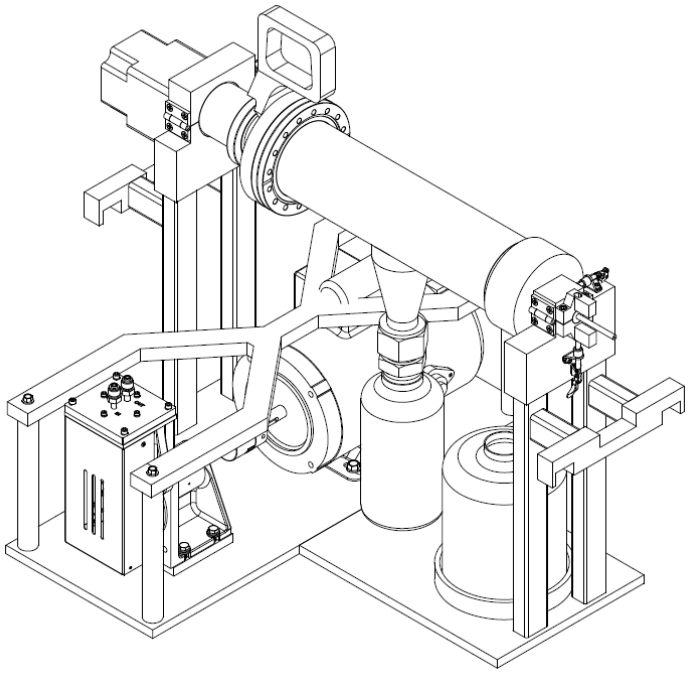


Figure 24. Reactor vessel and stand.

- **[ORNL]** Additional experiments were performed using divalent cation exchanged SAPO-34 zeolite membranes to assess the effect of pH on membrane performance for separation of tritium from water. As reported in December, Li and K exchanged membranes have shown the highest vapor permeance compared to several divalent cations, such as Ba and Sr. Synthesis and characterization of aluminosilicate zeolites such as Na-LTA (Linde Type A) is in progress. It is anticipated that these hydrophilic small pore zeolite membranes will improve the HTO permeance and selectivity. The milestone report for this task has been completed, and is currently under review and approval prior to distribution which is expected in early February (R. Bhave, B. Jubin)

SIGMA TEAM FOR ADVANCED ACTINIDE RECYCLE

- **[ANL]** In order to generate a large batch of ALSEP solvent in a timely manner, a third phase purification procedure of the HEHEHP extractant (the acidic component of the ALSEP organic phase) has been modified. The procedure was tested on a 250-g batch of HEHEHP (BOC USA), and the purity was verified by the 31P NMR. The modified purification procedure allow for minimizing the process time by at least a factor of 3. About 1 kg of the extractant will be purified and shared

among other project participants. The NMR spectra of the stock and the purified extractants are shown in Figure 25.

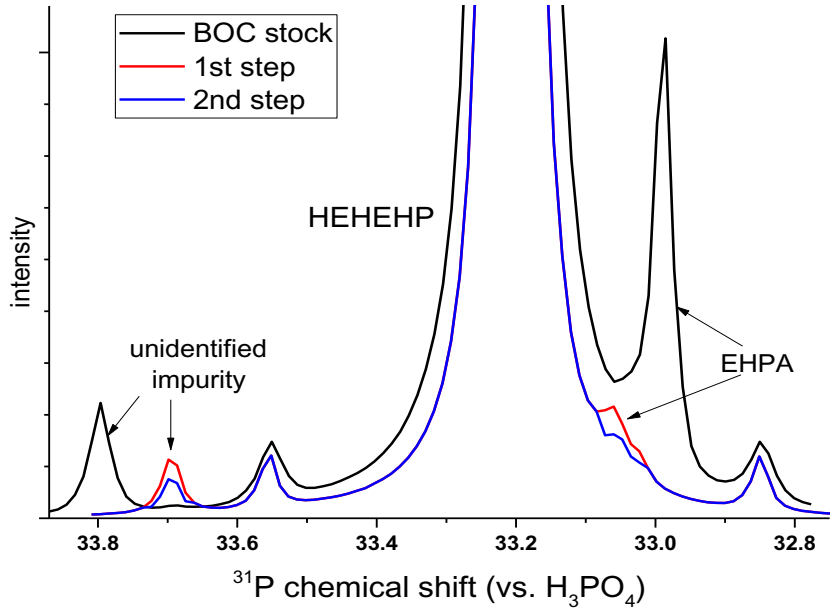


Figure 25. NMR spectra of BOC™ HEHEHP, purified by the ANL modified procedure: neat (black), after 1st purification step (red), after 2nd purification step (blue)

The resonance at ~33.27 ppm is the HEHEHP peak. The two resonances of equal height that are upfield and downfield from the HEHEHP peak by ~ 170 Hz (0.375 ppm) are the $J_{31P\text{-}13C}$, spin ½-½, coupled satellites. The fact that the two satellites together integrate close to 1.1 percent of the HEHEHP peak confirms this, because the natural abundance of C-13 is ~1.1%. The resonance at ~33.83 ppm is likely a neutral organophosphorus compound. The fact that the composition percent of this neutral compound does not decrease significantly through repeated third phase purifications supports this assumption as the neutral phosphate partitions with the HEHEHP. The peak at ~33.06 ppm is the di-acidic mono-2-ethylhexyl phosphonic acid, over the course of two purification steps its percentage relative to HEHEHP goes down from 4.12 to 0.158 (0.92 after 1st purification), conservatively calculated. Further studies are underway to determine if certain steps can be optimized or combined in order to speed up and simplify future purifications. (A. Gelis, A. Breshears)

- **[INL]** Efficiency testing was completed for the FY16 procured 3-D printed 2-cm centrifugal contactors from ANL. Contactor efficiency at total throughputs of 30mL/min and 40mL/min ranged from 95%-100%. Thus, contactor efficiency does not explain FY16 hot test results in these contactors where the Am distributions were considerably lower than batch contacts results achieved. Planning is currently underway for a single-stage Am extraction test, in analogy with this efficiency testing which was conducted using uranium. (B. Mincher, J. Law)
- **[INL]** Data collection has been completed for Am(VI) autoreduction measurements over a matrix of acid and total Am concentrations. After proper baseline corrections conducted in collaboration with Prof Chris Dares (NEUP collaborator), it is now possible to report reliable rate constants for Am reduction. Travis Grimes is currently summarizing these data and the techniques used to collect them for publication. These data are now being modeled by another NEUP collaborator team (Mezyk and Horne) to help elucidate the mechanism of the autoreduction of AmVI in nitric acid, using methods

originally developed under an INL LDRD that investigated the radiolystic redox chemistry of Np. (B. Mincher, T. Grimes)

- **[ORNL]** A paper with INL collaborators was accepted in *Inorganic Chemistry* - Grimes, T.S., Heathman, C. R., Jansone-Popova, S., Bryantsev, V.S., Goverapet Srinivasan, S., Nakase, M., and Zalupski, P. R. titled, "Thermodynamic, Spectroscopic, and Computational Studies of f-Element Complexation by N-Hydroxyethyl-diethylenetriamine- N,N′,N″,N″-tetraacetic Acid," *Inorg. Chem.*, 2017, DOI: 10.1021/acs.inorgchem.6b02897. This paper describes a new aqueous complexing agent for selective Am(III) binding that could be used in ALSEP or TALSPEAK applications. The new complexant features faster kinetics, which addresses a current challenge in finding systems sufficiently fast to operate efficiently in centrifugal contactors. It was learned that replacing one carboxylic acid sidearm of DTPA by a hydroxyl sidearm leads to faster coordination while sacrificing one chelate ring and weakening the bonding of one of the nitrogen atoms to the metal.
- **[ONRL]** Bruce A. Moyer delivered presentations titled, "Progress in Separations of Minor Actinides for Used Nuclear Fuel Recycle," to students and faculty at the Nuclear Engineering Department, Texas A&M University and the Department of Chemistry and Biochemistry University of Texas, Austin. The presentations reviewed the goals of the Sigma Team for Advanced Actinide Recycle (STAAR), significance of achieving these goals, STAAR scientific thrusts to address the above aims and questions, recent highlights of achievements, and future directions. (B. Moyer)
- **[PNNL]** The effect of different diluents on metal extraction in the ALSEP system is being investigated. Distribution ratios were measured using Eu-152 radiotracer from 0.3 mM Eu(III) solutions containing variable concentration nitric acid (0.1 – 3 M) for the ALSEP system (0.05 M T2EHDGA + 0.75 M HEH[EHP]) and for the independent constituent ligands (0.05 M T2EHDGA or 0.75 M HEH[EHP]) from four different diluents: n-dodecane, 2,2,4,6,6-pentamethylheptane (a branched isomer of dodecane), p-xylene, and 1,4-diisopropylbenzene (1,4-DIPB). In all cases, the ALSEP system showed synergistic extraction in the mid-acid regime, where neither extractant functions well independently (Figure 26). Similar behavior was observed for Am-241. The mechanism for this synergism and effect of the diluent on synergism are under investigation. It is observed that the distribution ratio in both aromatic solvents is depressed, yet follows the same overall trend, with enhanced synergism relative to the apolar diluent at the high-acid regime (3-5M). The Eu distribution ratios measured for the linear and branched dodecane isomers were nearly identical. (G. Lumetta)

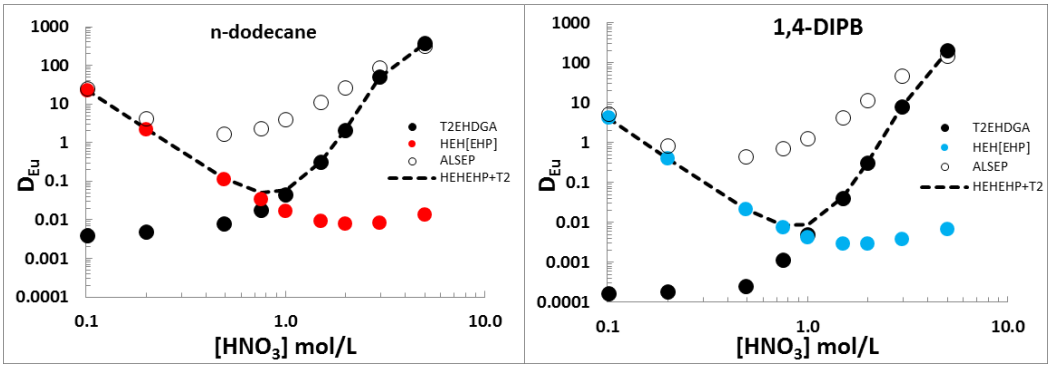


Figure 26. Eu distribution ratios (DEu) as a function of nitric acid concentration for extraction with the ALSEP extractants in n-dodecane (left) and 1,4-diisopropylbenzene (right).

SIGMA TEAM FOR OFF-GAS CAPTURE AND IMMOBILIZATION

- **[INL]** Work leading to completion of the Milestone M4FT-17IN030107017, "Develop long-chain organic iodide spiking and analysis methods," was performed this month. This work included developing, with the private company VICI Metronics, an iodododecane permeation tube for use in spiking iodododecane into the deep bed iodine adsorption test system process gas stream, targeting an iodododecane concentration of around 1-20 ppmv. Work control documents were updated to enable procurement and safe use of iodododecane in adsorption tests. Reagent-grade iodododecane was procured for preparing calibration standards to calibrate gas chromatographs intended for use during adsorption testing (N. Soelberg)
- **[ORNL]** The milestone report for M3FT-16OR030107027 has been completed and is in final management review. The report should be issued in early February. (S. Bruffey, B. Jubin)
- **[ORNL]** The neutron activation analysis (NAA) results from several tests in the VOG testing matrix were received. These tests were an attempt to resolve difficulties in closing the mass balance from prior VOG tests and tested the effect of various variables such as AgZ form (ground vs. pellet) and rate of iodine concentration. The total iodine recovered from the CH_3I tests performed was very low (~0.5%), which implies a potential issue with methyl iodide supply system. The gas from the CH_3I gas cylinder was sampled using a silver nitrate scrubber and was used on a short TGA iodine capture run at high concentration conditions. The results from both tests were indicative of little or no CH_3I in the supply cylinder. This issue will be addressed with the vendor and the potential to supply the required concentrations via permeation tubes has been explored and appears promising. (S. Bruffey, B. Jubin)
- **[ORNL]** The test system for comparison of AgZ and AgAerogel performance under VOG conditions underwent a substantial redesign to provide better gas mixing prior to contact of the sorbent bed with the feed stream, to facilitate easier in-test manipulation, and to eliminate any sources of leaks on the iodine feed stream. The iodine feed stream is now equipped with fittings certified to have a leak rate of less than 4×10^{-9} cc/s for He at ambient temperature. (S. Bruffey, B. Jubin)
- **[ORNL]** Two ~10 g samples of 3A molecular sieve were loaded in a sample holder that was then filled with 100% NO_2 then diluted with dry air to 75% NO_2. These were then placed in an oven for temperature aging at 40°C. These tests should yield information on the effect of NO_2 on the adsorption capabilities of 3A molecular sieves. (S. Bruffey, B. Jubin)
- **[ORNL]** Isotopic analysis of the caustic scrubber solutions collected from a test with a feed stream containing 2% v/v DCl (bal Ar) was completed and analysis of the samples indicated poor material balance on the deuterium which is captured in the aqueous solution as DCl(aq). Although presumably passivated from earlier experiments with Cl_2 feed, additional corrosion of the metal piping could have consumed the DCl, releasing D_2 or HD that will not scrub. To eliminate this concern, the system has been replumbed with all Teflon tubing and connectors. Scrubbing tests will resume in February. (S. Bruffey, B. Jubin)
- **[ORNL]** Data gaps have been extracted from the FY16 Engineering Evaluation of an Integrated Off-Gas System report. A conference call is planned with INL personnel for the latter part of February. (S. Bruffey, B. Jubin)
- **[ORNL]** A test matrix was designed to fulfill the milestone for Hot Isostatic Pressing of Engineered forms of I-Agz. The test matrix will focus on preparing samples at a range of temperatures and pressures. These samples will be characterized through durability testing to gain insight into the effects of pressing conditions. (S. Bruffey, B. Jubin)
- **[PNNL]** Milestone "M3FT-17PN030107036 - Supply Ag0-Functionalized Silica Aerogel for Aging Studies at Syracuse for NEUP Project and Support Characterization of Aged Samples," was

completed. This material will be used to gather additional experimental data at Syracuse University to elucidate a detrimental impact of aging on its sorption performance. (J. Matyas)

FUNDAMENTAL SEPARATION DATA/METHODS

- **[INL]** Analyses of two aromatic DGAs were completed. These compounds were TWE15 and TWE22, which are TODGA and MeTODGA derivatives, respectively, substituted with an aromatic ring on a methylene carbon. These compounds were synthesized at the University of Twente, Netherlands and supplied to INL by Forschungszentrum Juelich. At INL they were irradiated and then analyzed by LC-MS. These aromatic DGAs were irradiated to test the idea that the HNO3-radio-protection that is enjoyed by CMPO, but not the conventional DGAs is related to the CMPO phenyl ring. However, the aromatic DGAs are not protected by HNO3, and degrade observing pseudo-first-order kinetics and the results found here are not consistent with the original hypothesis. A third aromatic DGA, with a phenyl group substituted for two of the TODGA octyl groups was also irradiated. These samples were split, and analyses are currently underway at both INL and Juelich. This work was conducted in collaboration with the EU SACSESS partners. (B. Mincher)
- **[INL]** The INL principal investigator traveled to the Notre Dame Radiation Laboratory to help design pulse radiolysis experiments to measure radical reaction kinetics with diethylhexylbutyramide. These data contribute to the project in collaboration with CEA Marcoule, in which the radiation chemistry of the monoamides is being documented. (B. Mincher)

WASTE FORM DEVELOPMENT AND PERFORMANCE

Electrochemical Waste Forms

- **[ANL]** Electrochemical corrosion tests with RAW-6(U) are in progress. Available results show the addition of about 4 wt % trim Mo improves the corrosion resistance significantly under highly oxidizing conditions. This is attributed to the formation of $NiMoO_4$ passivating layer; the Mo content in RAW-6(Re) provided by the fuel wastes was not sufficient to maintain that layer. Additions of trim Cr and Mo benefit the performance of waste forms made with HT9 cladding. Figure 4a shows the potentiodynamic (PD) scan in a 10 mM NaCl solution adjusted to pH 8 with arrows indicating the voltages used in potentiostatic (PS) tests. The PS tests at 100, 200, 300 mV have been completed and the steady-state currents are shown in Figure 4b. Spikes are seen due to metastable pitting, but the surface remains stable. The corrosion currents for the stabilized surfaces are represented by the dashed line in Figure 4a, which can be used to calculate the Eh dependence of the corrosion rate in pH 8 brine solution. PS tests at 600 and 100 mV will be conducted next month. Additional PS tests will be conducted with RAW-6(U) in solutions adjusted to other pH values to derive an equation for the pH dependence of the corrosion rate at 300 mV. The results to-date indicate both the $ZrFe_2$ phase that hosts U and the steel phase that hosts Tc are passively stabilized. About 2 mg Tc-99 was added to a mixture having the RAW-6(U) formulation to make a 10-g ingot of RAW-6(UTc) to demonstrate the radionuclide release behavior from an optimized HT9-based waste form and application of the degradation model. (W. Ebert)

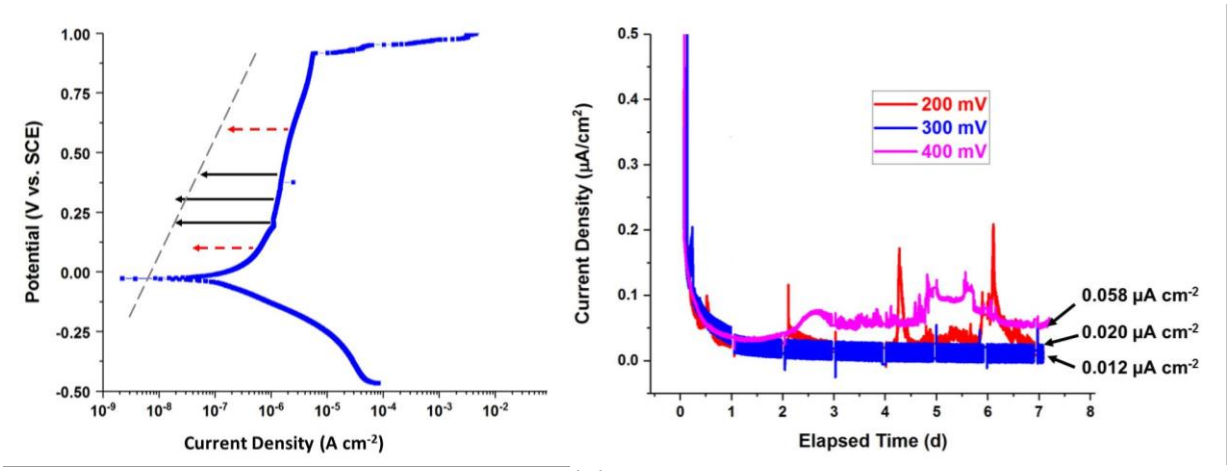


Figure 27. Electrochemical tests with RAW-6(u) in pH 8 brine solution: (a) PD scan and (b) PS tests.

Zirconium Recycle

- **[ORNL]** Analytical results were assembled and a final analysis was made to enable the zirconium mass balance for the upcoming level 2 milestone report. (E. Collins, B. Jubin)
- **[ORNL]** Transfer of the 772 g of high burnup cladding from the Building 7920 hot cells (where the CETE separations were done in 2009) to the Building 3525 hot cells (where the Zr cladding chlorination test equipment is located) was completed in January. The North Anna PWR UNF cladding (M5) had been irradiated to 63-70 GWd/MT and discharged in 2004. Preparations were made to use ~250 g of the cladding for the next chlorination test (2nd large-scale test), and an attempt was made to start the test. However, an immediate difficulty was encountered with pressurizing of the gas supply tube in the reactor, which is believed to be created by formation of solid $ZrCl_4$ salt in the small-diameter holes in the supply tube when the cold gas enters the heated reactor. A similar occurrence was encountered during the non-radioactive operability tests but was resolved by reaming the holes with a hand-tool, after which the problem appeared to be resolved. In the current hot cell operation, the same remedy is not possible. An alternative approach required that the test be shut down, the reactor emptied, and an attempt made to clear the gas supply holes using a wire brush. This was done but did not resolve the problem. Thus, a decision was made to cut off the tip of the gas supply line near the reactor door with a Dremel tool to open a larger diameter port for gas entry. A temporary frame was designed and built to hold the tube steady and the tube will be cut in early February. (E. Collins, B. Jubin)

Advanced Waste Form Characterization

- **[ANL]** Analyses of solutions from perturbed PCTs have been completed and results are being evaluated to parameterize the Stage 3 dissolution model. The tests provide insights into the effects of temperature, pH, and Si concentrations on the Stage 2 rate, residual rate, triggering of Stage 3 in the tests at 90 °C, and the Stage 3 rates. The results indicate changes in the temperature, pH, and Si concentration that occur during PA time steps can be represented as an instantaneous pulse of dissolved glass using same dependencies as in the Stage 1 model. A new series of tests using this method will be conducted to determine the composition threshold values for triggering Stage 3 in the glass degradation model. These will address the hypothesis that Stage 3 is triggered in two steps: the formation of an Al-based precursor on the gel (or clay) surface that is the nucleus of an Al-Si precursor to a zeolite. The ranges in pH, Al, and Si concentrations measured in the previous tests and

those provided in the ALTGLASS data base indicate the ranges that likely bound the threshold values that trigger these steps. Leachant solutions will be prepared with different concentrations of dissolved Al and Si and adjusted to different pH values within these ranges to determine (a) if Stage 3 is triggered, (b) the incubation time required to trigger Stage 3, and (c) the Stage 3 rate for particular solutions. (W. Ebert)

- **[ANL]** Bill Ebert participated in webinar on testing and modeling iodide-bearing waste forms that was hosted by PNNL to coordinate work at ANL, ORNL, and PNNL. (W. Ebert)

DOMESTIC ELECTROCHEMICAL PROCESSING

- **[ANL]** Recent tests revealed that the reference electrode voltage signal still contains an excessive amount of noise. Problems with instrument wiring have been eliminated as a possibility and other causes are being investigated. Tests to characterize the co-deposition cathode potential as a function of electrode area (immersion depth) and current are being carried out. The goal of these tests is to develop a protocol for characterizing the behavior of the co-deposition cathode as a function of operating conditions. After a short period of deposition at a given potential the cell is switched to open circuit and the potential of the co-deposition cathode vs. time is measured. Then the cell is switched to a closed circuit discharge configuration in which the anode and co-deposition cathode are directly connected and the potential and current vs. time data is collected. When the co-deposition open circuit potential indicates that the interface potential is controlled by the U^{3+}/U^{0} equilibrium there is still rare earth metal present beneath the surface because when the cell is switched to closed-circuit discharge the initial discharge current is nearly as large as the deposition current. This discharge current is attributed to the simultaneous oxidation of rare earth metal deposited on the co-deposition electrode with deposition of uranium on the baskets. (J. Willit)
- **[INL]** The report "Kinetics and Diffusivity of Uranium in FLiNaK and ClLiK; FCRD-MRWFD-2017-000408" was completed on January 31, 2017, as the deliverable for milestone "M3FT-17IN030106025: FY16 Fluoride Salt Study". A copy of the report was uploaded to the PICSNE system. This study performed cyclic voltammetry and linear polarization measurements in FLiNaK-UF_3 and ClLiK-UCl_3 salt mixtures at 773, 823, and 873 K. Parameters such as exchange current density, transfer coefficient, and diffusion coefficient were calculated and compared to values reported in literature. The calculated parameters of the FLiNaK salt mixture represent a scientific contribution as there is relatively little published information of this kind. Furthermore, these parameters could be useful for research and development of separations technologies in support of the molten salt-fueled reactor concept. (G. Fredrickson)
- **[INL]** The report "FY-16 Technology Gap Study Technical Report: Analysis of Undissolved Anode Materials of Mk-IV Electrorefiner; FCRD-MRWFD-2017-000360" was completed on January 18, 2017, as the deliverable for milestone "M3FT-17IN0306024: FY16 Technology Gap Study". A copy of the report was uploaded to the PICSNE system. This study reviewed historical process data from the treatment of EBR-II and FFTF reactor driver fuels in the Mk-IV electrorefiner at the INL Fuel Conditioning Facility. The purpose is to improve the predictive capabilities of the INL MASTERS pyroprocessing flowsheet simulation code with respect to actinides partitioning during electrorefining. From the viewpoint of modeling, the degree of uranium recovery from the used fuel directly impacts the factors such as the partitioning of transuranics, fission products, and zirconium, salt retention in the cladding hulls, and the characteristics of the metal waste forms. (G. Fredrickson)
- **[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. A technical report will be issued later in FY2017 (G. Fredrickson)

FUEL RESOURCES

- **[ORNL]** The bi-annual Fuel Resources Program Meeting took place at the University of South Florida on January 12-13. Participants included investigators from the Oak Ridge National Laboratory, Pacific Northwest National Laboratory, National Institute of Standards and Technology, and several universities. Presentations were given over the two-day meeting, and at the end of the second day, several participants toured a nearby desalination plant to determine if it would be an appropriate facility for future uranium extraction testing. (C. Tsouris)
- **[ORNL]** A review of uranium adsorption capacity for different adsorbents synthesized since 2011 and tested with natural seawater at PNNL clearly shows significant progress in developing materials with increasing uranium adsorption capacity during the past 5 years, under the Fuel Resources Program. (C. Janke)
- **[ORNL]** A new ligand has been computationally investigated using density functional theory and found to bind uranyl with comparable binding strengths as the imidedioxime (H2IDO). H2IDO is a weaker competing ligand with carbonate than the new ligand for complexing uranyl at seawater conditions. Another attractive feature of the new ligand is that it would form 1:1 instead of 2:1 complexes with vanadium. (V. Bryantsev)
- **[ORNL]** A new ligand based upon triazine that does not undergo cyclization is being synthesized. This ligand has demonstrated high affinity for uranyl while not exhibiting the high binding constant observed in the cyclic imidedioxime, resulting in a new ligand that will not remove the vanadyl oxygen. This new ligand suggests that vanadium will be eluted easier. (R. Mayes)
- **[ORNL]** EXAFS analysis using oligomers revealed no apparent contribution to uranium adsorption from the cyclic imidedioxime binding site, in support of previously reported work. Preliminary fitting of monodentate or chelating coordination of amidoxime with uranyl appears superior to η2-binding for small molecules, oligomers, and polymers. From these results, chelating still appears to be the best model for the uranium adsorption mechanism. Amidoxime to uranyl ratios ranged from 1.1:1 (small molecule) to 1.3:1 (adsorbent fiber) to 1.4:1 (oligomer), indicating 2:1 binding occurs with greater frequency for polymers and oligomers than for small molecules. One possible explanation for this is the large number of amidoxime groups located in close proximity to each other on both the adsorbent fiber and the oligomer. (C. Abney)
- **[ORNL]** A manuscript describing extraction of uranium with an amidoxime-functionalized porous aromatic framework and including XAFS analysis was submitted for publication in the *Journal of Materials Chemistry – A*, in collaboration with Prof. Ma of the University of South Florida. (C. Abney)
- **[ORNL]** The following invited "News and Views" article has been accepted for publication in *Nature Energy*: Tsouris, C. "Uranium Extraction: Fuel from seawater," *Nature Energy*, accepted, January, 2017. In this article, a paper accepted to be published in the same issue of *Nature Energy* in the near future, written by Cui and coworkers at Stanford University, and describing uranium recovery by an electrochemical precipitation mechanism (under FT- 17SL03020106), is discussed in relation to the overall effort of uranium recovery from seawater. (C. Tsouris)
- **[PNNL]** Gary Gill and Li-Jung Kuo attended the Fuel Resources, Uranium from Seawater bi-annual review at the University of South Florida in Tampa on January 12th and 13th. Gary gave an overview of recent marine testing activities and Li-Jung summarized the recent work on the reusability of amidoxime-based polymeric adsorbents. Major highlights of these presentations include: (G. Gill)
  - ORNL has produced several new amidoxime-based adsorbent formulations in the last half-year with adsorption capacities that exceed 5 g U/kg adsorbent in 56-days of exposure.

  - The latest LCW adsorbent formulation has reached 6 g U/kg adsorbent, with a half-saturation time of 16 days, and a low V/U mass ratio of ~ 1.2 in 56 days of exposure.
  - Marine testing at the Broad Key Island field site off the coast of Florida suggests that amidoxime-based adsorbents can be expected to retain 6-7 g U/kg adsorbent in 56 days of exposure in ambient seawater off the coast of Florida and Gulf of Mexico.
  - Recent investigations into biofouling at Broad Key Island support previous work at PNNL suggesting that the biofouling impact on adsorption capacity is around 30%
  - Studies of the reusability of several amidoxime-based adsorbents reveal that adsorption capacities decrease with use, such that after the 5th use the adsorbents have only about 25-30 % of their original capacity.
  - Multiple lines of evidence suggest that a major reason for the loss in capacity of amidoxime-based adsorbents is due to degradation of the amidoxime ligand during seawater exposure.
- **[Stanford]** A new type of sorbent material has been synthesized and is being investigated for U extraction using electrochemical method. (C. Liu)

CoDCon Demonstration

- **[ANL]** Based on input from the CoDCon Demo team, several variants of the initial baseline flowsheet will be run to investigate the impact of changing the location of the reductant feed to the second segment of the process. We have received distribution literature data on the behavior of U(IV) under variable nitric acid concentrations that was compiled by PNNL to aid in running these simulations using the AMUSE code, which is being adapted to better track U(IV) in process. (C. Pereira)
- **[PNNL]** A report describing the design of the Phase 1 CoDCon testing system was issued. Included in the report are descriptions of: 1) the proposed CoDCon flowsheet to be tested, 2) the solvent extraction system to be used, 3) the electrochemical equipment that will be used to generate the required U(IV), 4) the on-line monitoring system, and 5) the equipment to be used for batch modified direct denitration to convert the U/Pu nitrate solution from the solvent extraction to the mixed U/Pu oxide. (G. Lumetta)
- **[PNNL]** Collection of the spectral training sets required to develop the chemometric model to be used for real-time monitoring of uranium and plutonium concentrations during the CoDCon testing continued. A spectroelectrochemical system was established to efficiently measure a wide variety of solution conditions with minimal consumption of plutonium. Spectral data sets have been collected for Pu(III), Pu(IV), Pu(VI), U(IV), U(VI), as well as for mixed Pu(IV)/Pu(III)/U(IV) and Pu(IV)/U(VI) systems over a range of nitric acid concentrations from 1 to 6 mol/L. Spectral data sets that remain to be measured include mixed sets of U(IV)/U(VI), an expanded concentration range of Pu(VI) up to 1 mmol/L Pu(VI), and organic-phase U(VI) and Pu(IV) species. These remaining data sets should be collected in the coming month. (G. Lumetta)
- **[PNNL]** Acquisition of the spectroscopic system equipment is proceeding according to schedule. Purchase orders for all equipment have been submitted and communications with the vendor indicate there are no anticipated problems with delivering the equipment on time. Additionally, system components required to install monitoring equipment in the glove box have been approved and ordered. (G. Lumetta)
- [**SNL]** The CoDCon model has been built in Matlab Simulink. This model will be benchmarked against the testing at PNNL and can be used to explore a variety of process variations. Process control measurements have been included in the model. (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]** Planning continued for the February joint Modelling/Simulation Workshop with MRWFD, and the March joint Working Group Meeting with MRWFD. Submitted an article to DOE NE ASI newsletter on the level and density sensor for molten salt.

CAM & Technical Support

- **[INL]** Continued preparations for the Modelling and Simulation Workshop that will be held in Phoenix, AZ, Feb. 1-2 and the MPACT/MRWFD Working Group Meeting that will be held March 28-31 in Albuquerque, NM.

SAFEGUARDS AND SECURITY BY DESIGN - ECHEM

Microfluidic Sampler

- **[ANL]** Preparation of the gloveboxes that will house the pneumatic generator for tests with uranium-bearing salt and the flow cell continue. Design work on the flow system continues.

Modeling and Simulation for Analysis of Safeguards Performance

- **[ANL]** Coding of the AMPYRE code to decouple unit operations to allow independent timing of functions and sequencing of operations continues. Initiated development of an oxide reduction model, comparable to the DyER electrorefiner model. The model is being developed in MATLAB to operate in standalone mode or to interface with DYER and AMPYRE.

Electrochemical Sensor

- **[INL]** Surrogate ion exchange work continues to familiarize new researcher with methodology. The required training for accessing FASB (where uranium work will be performed) was completed. The required qualification training for working with radioactive materials using an actinide glovebox in FASB has been scheduled for April.

Sensor for Measuring Density and Depth of Molten Salt

- **[INL]** The height gauge has been received. Work in HFEF was slowed down to reduce spending rate.

Voltammetry

- **[ANL]** Several test parts for the electrochemical sensor were machined out of a ceramic-mica composite to improve electrical isolation of the metal electrodes. A 3D-printed prototype module fit with the ceramic-mica components and metal electrodes is being used to evaluate sensor performance. Simulations examining the optimal positioning of the reference electrode with regard to the elimination of cross-talk with the sensor is underway.
- **[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 feature is lengthy, entailing upgrades to 36 existing subroutines and 10 new subroutines. Debugging is showing good progress. Initial serial execution using the "LCC" pyroprocessing facility model was accomplished inclusive of mesh-tally and pulse-height detector tallies for moving material. Work on the MPI coding is underway; the MPI portion coding was revamped during the MCNPX/MCNP5 code merger, so the moving-objects MPI coding is being modified accordingly as it is implemented in MCNP6. Once completed, simulations using parallel (MPI) execution will be possible. MPI execution will 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. A presentation was prepared for the February 1, 2 MRWFD-MPACT Mod-Sim Workshop in Phoenix, AZ.

ADVANCED INTEGRATION

Advanced Integration (Methods)

- **[LANL]** Modified the process model (ExtendSim) to produce output files directly for Process Monitoring (PM), Nuclear Material Accountancy (NMA) and additional sensors, including a diversion after the feed inventory tank. The data from the process model (ExtendSim) consist of deviations for material unaccounted for (sigma MUFs) as a function of time over the reprocessing duration. Advanced Integration (AI) model development has been done where the sigma MUF's from the ExtendSim output files are converted to probability of detection based on a detection goal, the sigma MUF and a mean by random sampling of a normal distribution and determining how many data points are less than or equal to the detection goal. Focused on the Bayesian extensions for detecting off-normal behavior in nuclear material reprocessing plants. In particular, Bayesian change-point models for each sensor data stream were investigated, including sequential application of the models at half-day and full day intervals using simulated data from the ExtendSim model. Efforts are underway to use the output from the Bayesian change-point models applied to each sensor under consideration in a data fusion process to combine sensor information. Optimal decision rules combining the posterior output from the Bayesian change-point analyses of each sensor stream are continuing to be developed.

Advanced Integration (Facility Models)

- **[SNL]** Examined the interfaces between the SNL mod/sim codes and other labs' codes to determine ways to link capabilities or develop integrated models in the future. ALE-3D simulations for the spent fuel ratio grid refinement are complete. Confirmatory modeling with CTH will be performed in the upcoming months. An abstract on this subject will be submitted to the 58th Annual INMM Meeting.
- **[LLNL]** Completed calculations and sent the results to SNL. Are making further runs which incorporate the p-alpha porosity model and studying the sensitivity of melt parameters used in the model. Will work with SNL to publish the results at an INMM conference.

MIP Monitor and CoDCon

- **[PNNL]** Traveled to SRNL to gather final sets of processing data in the sampling aisle. H-Canyon has processed a total of three separate batches of used nuclear fuel this fiscal year. Data has been collected at various locations in the sampling aisle including purified uranium, low-activity waste, and high-activity waste streams. The data was processed at UTK and current chemometric analyses are being attempted. Work at UTK in January continued on evaluating alignment procedures. It was determined a global alignment across all measurement locations is not strictly necessary. Alignment

is now focused on materials measured at the same location or same stage in the reprocessing stream (e.g., all dissolution and head-end measurements are aligned to each other). This supports the deployment scenario for the MIP Monitor, where materials will be evaluated relative to the expectation for that location. This will also support tracking material through the reprocessing system. A summary was submitted to the ANS Annual Meeting comparing alignment procedures and resulting PCA models. A journal article was accepted in NIM-A describing the MIP Monitor work on fuel characterization completed in FY12. A journal manuscript is in preparation discussing the numerical experiment simulating a postulated diversion scenario presented at ANS Advances in Nuclear Nonproliferation Technology and Policy Conference.

EXPLORATORY RESEARCH / FIELD TESTS

Microcalorimetry

- **[LANL]** Completed specification of all components to be used in the high-bandwidth array readout demonstration. The purchase order for high-frequency superconducting coaxial cables has been approved. In the cryostat, a failed electrical connection was identified which prevents operation at low temperature. However, we expect that this connection can be repaired at LANL and does not significantly affect the project schedule. Katrina Koehler successfully presented her dissertation proposal at Western Michigan University, which focuses on the application of microcalorimeter detectors to electron capture spectroscopy. Her dissertation proposal was well received by her advisory committee.

High Dose Neutron Detector

- **[LANL]** The testing of the repaired parallel-plate detector is currently ongoing using LANL high activity gamma source. Discussions were initiated with INL regarding possibilities of field test of the parallel-plate detector.

In situ Measurement of Pu Content in U/TRU Ingot

- **[INL]** Using the new lid, three temperatures were characterized with 14 g aluminum in the top-loading furnace of the Engineering Development Lab (EDL) argon glovebox. Shown in attached Figure 1 is the external thermocouple measurements versus the internal thermocouple measurements. The correlation of the data is very good and the data aligns very well with previous data.

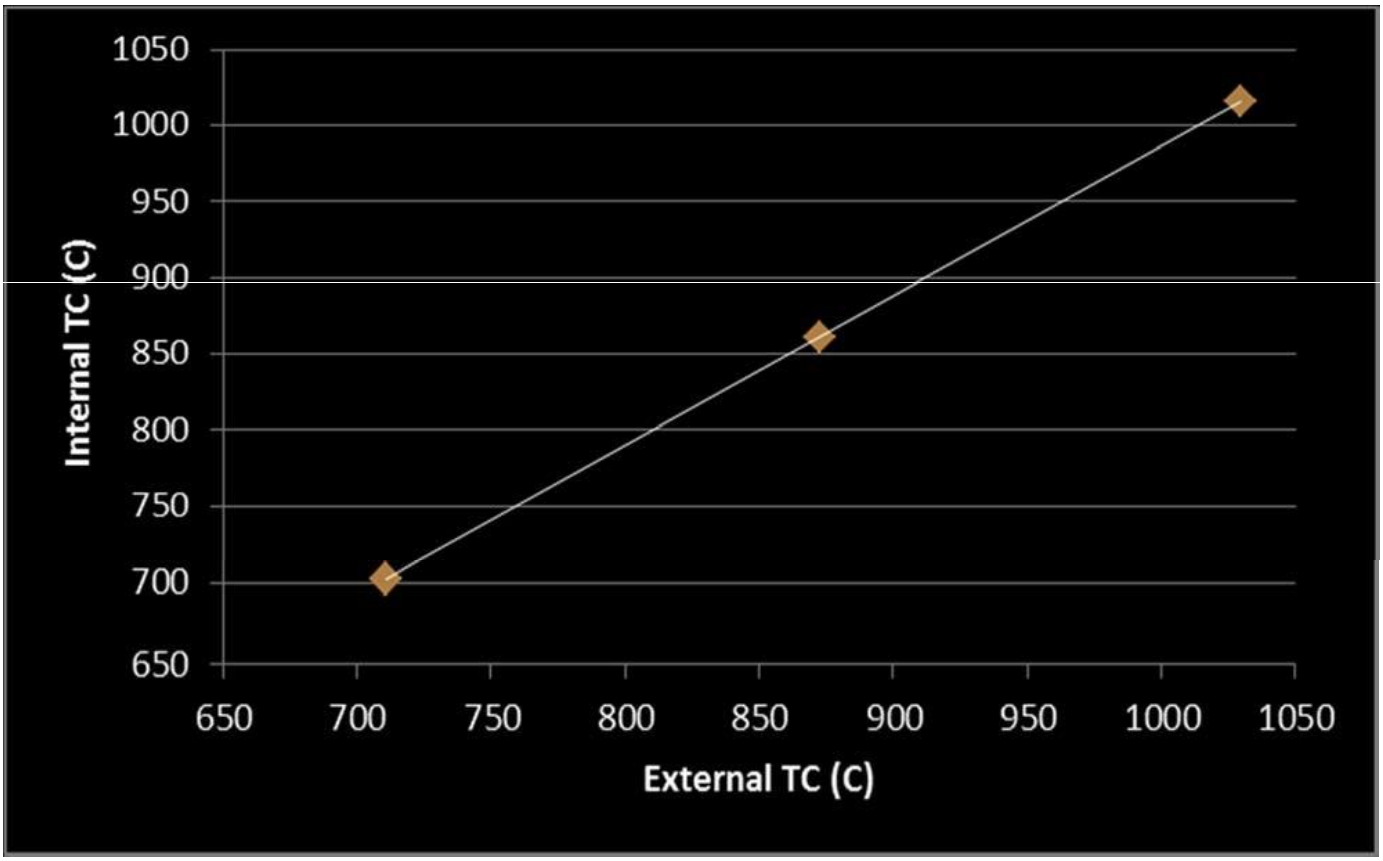


Figure 1. Top-loading furnace characterization with new lid and Al

H-Canyon Support

- **[SRNL]** Planned for an early February visit from PNNL researcher, tracked H Canyon processing schedule and providing updates, and coordinated training for PNNL researchers.

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

Fuel Cycle Options Campaign

CAMPAIGN MANAGEMENT

- **[INL]** The NTD provided input to the guidance for the FY 2019 Integrated Priority List activity by DOE/NE concerning the Fuel Cycle Options campaign in the Fuel Cycle Research & Development program, identifying specific items to be considered for funding as part of DOE/NE FY 2019 budget submission planning.
- **[INL]** The NTD worked with DOE/NE-4 Federal program managers on their implementation of the Technology and System Readiness Assessment process that had been developed by the Fuel Cycle Options campaign, applying the process to a high-level evaluation of Accident-Tolerant Fuel concepts in collaboration with the Advanced Fuels and Fuel Cycle Options campaign.

EQUILIBRIUM SYSTEM PERFORMANCE (ESP)

Equilibrium System Analyses

- **[ANL]** Submitted a full paper to FR'17: Nicolas E. Stauff, Roberto Ponciroli, Taek K. Kim and Temitope A. Taiwo, "Benefits of the Sodium-cooled Fast Reactor Technology for Load Following Applications".
- **[ANL]** Contributed presentation material to the package bring developed by ORNL for briefing DOE-NE Managers on MSR technologies in mid-February.
- **[ORNL]** A first draft of the each of the 6 presentations for the MSR Seminar have been produced and sent to Campaign management and Federal Manager for review. A teleconference call was held to discuss the feedback and final drafts are underway.
- **[ORNL]** An abstract entitled "Fuel Cycle Analysis of Thermal and Fast Spectrum Molten Salt Reactors" has been submitted by Ben Betzler for the Global 2017 conference.
- **[INL]** Fleshed out the scope for the equilibrium fuel cycle analyses with the NTD and initiated development of an annotated outline to guide the analyses and the final report.
- **[INL]** Collecting information on issues related to diurnal grid load balancing with increasing shares of electricity supply coming from non-dispatchable technologies in support of the load following subactivity.
- **[ANL, BNL, INL]** Under the NEUP project of Vanderbilt University (NEUP 13-5220), the following three fuel cycle data packages (FCDP) related to thorium fuel utilization were developed. The FCDPs are under review by ANL, BNL, and INL.
  - 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)
- **[ANL]** Collecting information on a Swedish small modular reactor, SEALER (Swedish Advanced Lead Reactor). The SEALER uses 19.9% enriched uranium oxide fuel to generate 3 – 10 MW over 10 - 30 years. The targeted markets are Artic communities in Canada. The first SEALER units will be transported back to a centralized recycling facility. The plutonium and minor actinides may be separated and converted into an inert matrix nitride fuel for indefinite recycle in SEALER reactors.
- **[ORNL]** In support of the MSR Seminar, a series of metric calculations were completed and documented for the range of MSR options previously analyzed. This includes U3/Th, U/Pu, and fast

and thermal options, as well as replacing the LWR with an MSR in EG29. This information is to be used to enable the comparison of fuel cycle performance in the seminar presentations.

Economics and Financial Risk Assessment

- **[ANL]** Started the identification of the direct/indirect cost contributions to the cost of construction of an aqueous reprocessing facility based on a detailed study by DuPont de Nemours for an industrial-scale plant developed in 1961.
- **[ANL]** The work on the economics of pyroprocessing progressed with the acquisition of a summary report sponsored by the Landmark Foundation, to investigate the cost of pyroprocessing LWR SNF. The report included a cost analysis performed by Merrick and Co. (an architect engineer firm with experience in, among other things, nuclear construction) of a 100MT/y facility for which the design was developed by researchers at ANL. Key considerations and levelized unit cost calculations from the report have been summarized.
- **[ANL]** The work on the economics of fast reactors progressed with the identification of a 2004 paper from Russia (Atomic Energy Journal) with some cost information on the BN800. However, the paper was written before the project completion and therefore did not include the subsequent escalation in costs.
- **[INL]** Working on the time series analysis to update the Cost Basis relevant to uranium and SWU prices, evaluated alternative time series models and methods of analysis. Reviewed the multi-mineral index approach and the MIT elasticity analysis, analyzing how a comprehensive time series analysis generates more information for an analyst to use. The search led to the Geometric Brownian Motion model, which is now being analyzed in terms of applicability and data requirements.

Maintenance of Fuel Cycle Catalog

- **[SNL]** Only administrative work was performed for this work package during January because personnel were not available and because funding did not become available until mid-month.

DEVELOPMENT, DEPLOYMENT AND IMPLEMENTATION ISSUES (DDII)

Technology and System Readiness

- **[BNL]** Provided input on the definition of Critical Technology Elements (CTEs) to DOE-HQ for Accident Tolerant Fuel (ATF) cladding concepts proposed by industry (Areva, GE, Westinghouse). The definition of CTEs is the first step in the application of the Technology and Systems Readiness Assessment approach described in the FY16 report [Technology and System Readiness Assessment Process for R&D Evaluation, FCRD-FCO-2016-000110, June 30, 2016]. DOE-HQ will conduct an initial implementation of the proposed approach to these ATF options.
- **[INL]** Working with the Materials Recovery and Waste Form Development campaign on a technology and system readiness analysis of the aqueous recycle portion of the fuel cycle. Divided the aqueous recycle system into subsystems to aid the analysis. Defined the elements and started the Critical Technology Elements (CTEs) evaluation of the fuel chopping and leaching subsystem.

Transition to Alternative Fuel Cycle

- **[INL]** Generated fuel recipes and detailed LEU mass flow information for each recycle modeling transition from the LEU startup core to the Pu/NU equilibrium core for the EG29 SFR. This information will allow VISION to model the transition in detail during scenarios studies.

- **[INL]** Reactor physics calculation results for startup of a high breeding ratio SFR on LEU followed by transition to a Pu/NU core were shared with ANL. The design is intended to support the EG29 transition studies and involves minimal design modifications with no change in the number of assemblies, but some enrichment of blankets for the initial core. The analysis shows that the Pu/NU core is achieved after two recycles, though isotopic compositions of Pu238 and Pu242 continue to evolve for 6 recycles.
- **[INL]** The TRU nuclide recipes for the LEU transition analysis have been prepared for both high and low breeding SFR cores utilizing REBUS-3/MC2-3. These analyses support EG24 and EG29. Next, the FY16 analysis of EG23 will be redone to use zero growth instead of 1% growth.
- **[ANL]** Reactor physics calculation was performed to evaluate the feasibility of transition from LEU SFR to Pu SFR with minimal design modification. The minimal design modification mainly means that the LEU SFR and Pu SFR systems need to have the same driver assembly loading pattern. Blanket assemblies are replaced by reflectors to adjust the Pu production rate if necessary (e.g., for EG23 transition starting with a high-breeding core). The major conclusion is that for all four EGs (EG23, EG24, EG29, and EG30), the transition from LEU SFR to Pu SFR with minimal design modification is feasible.
- **[ANL]** Additional sensitivity study was conducted to evaluate power sharing ratio between SFR and PWR in EG29 adopting new recycle strategy, discharged Pu from PWR is recycled into the SFR rather than recycled in the PWR. This recycle strategy requires mass balances between two streams: 1) recovered Pu from SFR blanket and charge Pu in PWR, and 2) discharged Pu from PWR and required Pu for SFR driver. The result shows that the electricity power sharing ratio of SFR is dependent on the Pu content in the driver fuel. The ratio is ~80% with 17% Pu content, but decreases to 60% with ~30% Pu content.
- **[ANL]** Successfully modeled in DYMOND the new EG30 steady-state fleet of SFRs and PWRs in which the PWRs are fueled with MOX fuel using TRU recovered from SFR blankets only and TRU recovered from discharged MOX fuel are recycled in the SFR driver. These new directional mass flows avoid multi-recycling of TRU in thermal reactors and ensures a constant high quality TRU vector fed into the PWRs. For no growth conditions, this strategy may result in a reduction of the fleet share of PWRs to 16% (vs. 84% SFRs).
- **[INL]** Set up end-state verification test case for EG-30 transition scenario in VISION. This included addition of recovered LEU management at both higher and lower enrichment levels to maximize the reuse of RLEU without reenrichment.
- **[LLNL]** W. Halsey participated in discussions of ongoing transition analysis work.
- **[ORNL]** Initial models of the EG30 transition analysis have been developed in ORION, and following some iterations on the specification, the results are looking promising when compared with the results from DYMOND.

Transition Economics

- **[INL]** As part of the bi-weekly coordination meetings on economics, continue to discuss economic aspects important to the formulation of transition scenarios. The primary scenarios will not consider economics directly, but alternative scenarios will consider methods to maximize contact-handled fuel fabrication and maximizing the load factor for reprocessing and remote fuel fabrication for the SFRs.

Regional and Global Impacts

- **[LLNL]** W. Halsey participated in discussions of the evolving nuclear energy business and socio-political environment via email and telephone.

- [PNNL] Investigating alternative levels of long-term nuclear energy deployment and their impact on the broader energy system. Exploring range factors that affect nuclear energy use, such as nuclear capital costs, retirement schedule, competing technology costs, and future energy policies.

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.
- The Level 2 milestone "Prepare 2017 Nuclear Technology Transfer Sheets" was completed on time.
- Precision gamma-scanning (PGS) of two FFTF elements was completed. Gamma scanning is being performed to verify element burnup estimates and to assist with location determination for physical sampling.
- Four irradiated FFTF MOX fuel elements were successfully declad using installed IRT head-end equipment.
- Management reviews to operate the oxide reduction system with irradiated material were successfully completed.
- Modified hardware for the IRT electrorefining system was received in January, and thermal testing initiated.
- Modifications necessary for installation of the scalability testing glovebox were completed in the Fuel Cycle Facility. The glovebox is planned to be physically installed in February.

ELECTROCHEMICAL RECYCLING ACTIVITIES:

- Head-End: In January, head-end equipment was used to declad four irradiated MOX fuel rods (for a total of five). Fuel recovery averaged greater than 98%. Less than 3% of the recovered fuel are fines (less than 45 µm). The fuel material greater than 45 µm was loaded into a universal basket in preparation of oxide reduction operations. Precision gamma-scanning of two FFTF elements was completed. Gamma scanning is being performed to verify element burnup estimates and to assist with location determination for physical sampling.
- Oxide Reduction System: A management self assessment for operations with irradiated fuel was completed in January and scheduled for completion in January. Fabrication of improved designs for various system components has been completed and components were transferred into the HFEF hot cell for installation in the Oxide Reduction System.
- Electrorefiner System: Modified hardware for the IRT electrorefining system was received in January and was used to perform thermal testing in the North Holmes Laboratory before being transferred to the Remote Mockup shop at MFC. Remote qualification of the modified hardware was completed and the equipment was staged for installation in HFEF. Phase III equipment qualification of the IRT electrorefiner will continue in February.
- Remote Distillation Systems: Phase III equipment qualification of remote distillation system RD1 continued in January. Preparations continued for cadmium and salt distillation process parameter development in the prototype distillation apparatus in a glovebox at the Engineering Development Laboratory.

ELECTROCHEMICAL RECYCLING ACTIVITIES: (CONTINUED)

- Waste Form Development: Waste form samples from collaborators in the ROK were transferred to PNNL and ANL. Testing initiated to determine durability and release rates from these samples. Engineering drawings for existing equipment to be used in IRT waste form demonstrations are in review.

JFCS FUELS:

- Fuels – IRT: In January the casting and sampling equipment was moved from the main table to the extension table to allow head-end processing to commence at HFEF window 10M. Additional tests with gravity casting operations are planned for the March timeframe.
- Fuels – Critical Gap: An issue in the casting laboratory glovebox has which has delayed some critical gap activities. However, fuel cladding chemical interaction (FCCI) work using TiN as a diffusion barrier continued.

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:

- Contributed to the NE-4 Integration Meeting 25 January
- Implemented change in PICS to remove the "AT" designation in Deliverable Form
- Initiated BCP's to add in additional funding for anticipated funding under current CR

QUALITY SUPPORT:

- **[ANL]** Attended QA PoC Meeting at SRNL in January 2017. Attended regularly scheduled telecons. Work continues on surveillance due by the end of June 2017.
- **[BNL]** Participated in QAPOC meeting at the SRNL on Jan. 11, 2017 and biweekly POC conference call.
- **[INL]** Working 2 projects: 1) material recovery 2) AFT deliveries.
- **[LANL]** Nothing reported.
- **[LBNL]** Annual refresher training and audit preparation
- **[LLNL]** Nothing reported.
- **[ORNL]** Continued to review ORNL FY17 work packages and deliverables to determine appropriate candidate activities for review during the upcoming FCR&D QA audit in March.
- **[PNNL]** Attended the FCT QA POC Annual Meeting on January 11th at SRNL and presented the status of PNNL activities for FY2017. In addition, assisted the DOE FCT QA Manager in performing a QA Review of the SNRL QL3 and QL4 FCT deliverables on January 12th and 13th.
- **[SNL]** Nothing reported.
- **[SRNL]** SRNL hosted the QA POC meeting and Review visit at the SRNL(badging, agenda, review, tours, etc.) on January 11-13th, 2017. All DOE laboratories across the DOE Complex attended. A review was conducted on the Spent Fuel and Waste Disposition Campaign and Fuel Cycle Research and Development Campaign. Program is working accordingly to quality assurance program document.

COMMUNICATIONS:

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

INFORMATION MANAGEMENT:

- Identified task-based activities continue.
- The software platform upgrade activities are scheduled to begin in March 2017.

REACTOR DIGITIZATION:

- The reactor core model is being detailed. The connection between the top of the core and the top of the vessel is being completed. Details on the structure and components used for fuel and maintenance are being included. PDF format records continue being made of the models to develop a survey of the reactor features.

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

AFCI-HQ Program Support

UNIVERSITY PROGRAMS

Site: University Research Alliance at West Texas A&M University in Canyon TX, and the following universities: University of Arkansas, University of Idaho, Vanderbilt University, University of Texas at Austin, Georgia Institute of Technology, Pennsylvania State University, Rensselaer Polytechnic Institute, University of Nevada at Las Vegas, University of Michigan, University of Notre Dame, Northwestern University, Boise State University, University of Florida, Idaho State University, Virginia Commonwealth University, Clemson University, and other universities.

Universities engaged in Nuclear Technology research via URA programs since 2001: Boise State University
Boston College
Clemson University
Colorado School of Mines
Georgia Institute of Technology
Idaho State University
Florida State University
Kansas State University
Massachusetts Institute of Technology
Missouri University of Science and Technology
North Carolina State University
Northern Illinois University
Northwestern University
Ohio State University
Pennsylvania State University
Purdue University
Rensselaer Polytechnic Institute
Rutgers University
Texas A&M University
University of Arkansas
University of California at Berkeley
University of California at Santa Barbara
University of Chicago
University of Cincinnati
University of Florida
University of Idaho
University of Illinois at Urbana-Champaign
University of Michigan
University of Missouri
University of Nevada at Las Vegas
University of New Mexico
University of North Texas
University of Notre Dame
University of Ohio
University of South Carolina
University of Tennessee at Knoxville
University of Texas at Austin
University of Virginia
University of Wisconsin
Vanderbilt University
Virginia Commonwealth University
Washington State University

INNOVATIONS IN NUCLEAR TECHNOLOGY R&D AWARDS (FORMERLY INNOVATIONS IN FUEL CYCLE RESEARCH AWARDS)

Summary Report

- University Research Alliance completed preparations for the 2017 Innovations in Nuclear Technology R&D Awards (formerly the Innovations in Fuel Cycle Research Awards). The timeline for the 2017 awards was finalized and the web site updated.
- The DOE requested an additional award category for this year's awards: Advanced Reactor Systems (including material science, advanced alloy development and testing, nuclear physics, nuclear reactor thermal hydraulics, fast reactor concept development, advanced reactor design). This brings the number of prize categories to seven for 2017.
- The program was announced on January 23. The announcement was made through emailing information about the program to university faculty in relevant disciplines.

- 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 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 by about 25% over the past three years but the pool of potential applicants is still a small pool. 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 announcement will be sent to all parties several times to provide every eligible student the opportunity to apply.
- Historically, the vast majority of applications are received in the final week, with most of those being received in the 24 hours before the deadline.
- 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.