Report to NEAC

Nuclear Technology R&D Subcommittee

Meeting of October 27, 2016

Washington, DC

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Al Sattelberger (Chair), Carol Burns, Margaret Chu, Raymond Juzaitis, Chris Kouts, Ronald Omberg, Joy Rempe, John Stevens, Dominique Warin

I. Introduction

The agenda for the October 27, 2016 Nuclear Technology R&D Subcommittee meeting is given below. The meeting provided members an overview of several research efforts funded by the DOE Office of Nuclear Energy's Nuclear Technology Research and Development (NTRD) Office and related research that is coordinated with the NTRD program. This meeting started with an overview of the recent DOE-NE reorganization, followed by a FY17 budget overview. Sekazi Mtingwa has resigned from the Subcommittee. Two members of the Subcommittee were absent, *viz*., Margaret Chu and new member John Stevens.

Agenda
Chair: Dr. Alfred P. Sattelberger
Location: Argonne National Laboratory, Bldg. 401 (Advanced Photon Source), Room A5000

8:30	Light Breakfast, Bldg. 401, Room A5000
9:00	Executive Session
9:15	Overview – Office of Nuclear Technology Research & Development (NE-4)
9:30	FY17 Budget Overview & Status
9:45	Modeling and Simulation of Fuels
10:45	Break
11:00	Materials and Chemical Technologies (NE-43) Direction &Strategy
11:30	Advanced Reactor R&D (NE-41)
12:15	Lunch
1:00	Accident Tolerant Fuels – Overview & Update
2:00	Cladding for Fast Reactor Fuels
3:00	Material Protection and Control (MPACT)
4:00	Break
4:15	INL Irradiation Testing & Capabilities Update (TREAT)
5:00	Executive Session

Our report is organized more or less along the lines of the agenda.

II. Reorganization and the new Office of Nuclear Technology Research & Development (NE-4)

Highlights and Observations

- Merging Advanced Reactors with Fuel Cycle Technologies in NE-4 seems to be an excellent organizational means for enabling the conceptualization and planning of full "nuclear systems". If exploited well, this could be a means for promoting enhanced sustainability of the nuclear clean-energy option into the future.

- The technology readiness level (TRL) focus for NE-4 (lower) and NE-5 (higher) is a novel approach, but will require managed coordination and careful budget planning to achieve desired success. Otherwise, longer-term R&D in NE-4 may always be at risk in budget-constrained scenarios. Steady advancement of the technology development timeline will require persistent attention.
- Segregating waste management issues in NE-8 appears to be prudent and consistent with the outcome of the Blue Ribbon Commission Report. However, if it becomes apparent that this organizational element will be eventually separated from NE, then certain critical capabilities may have to be retained within NE to ensure that a life-cycle approach to fuel management continues to underpin a systems approach for development of advanced nuclear systems.
- The assignment of NEAMS and CASL to NE-5 seems reasonable given the importance of ensuring relevance and access to a broadly-based user community (e.g., through GAIN). However, careful management of the NE-4/NE-5 interface will need to be maintained in order to realize the benefit of transformational impact resulting from high-fidelity, multi-scale, multi-physics simulation in support of all program elements of NE. In this regard, the conceptual design of the Test Reactor in NE-4 must be informed by the modeling and simulation program so as to ensure a facility that is maximally instrumented to promote validation of advanced simulations.
- Careful attention to the interface between NE-3 (Infrastructure Programs) and NE-7 (Site Operations) will need to be maintained to avoid the unintended, but potential emergence of "two site offices" interacting with the contracting entity at INL.

Recommendations

- Given the NE reorganization, as well as inevitable changes that may derive from the imminent change in Administrations, it is recommended at NE immediately engage in a strategic planning effort to maintain program coherence through the transition period.
- At this time, it is not clear what scope will be assigned to activities in the Office of Budget and Planning. This office may be the appropriate home for a permanent strategic planning cell that will maintain close coordination between NE strategic planning, program planning, and budgeting.
- Some thought should be given as to how the various key interfaces among constituent program offices in NE (i.e., NE-3, 4, 5, 6, 7, and 8) will be coordinated and balanced. Some of these

interfaces are highlighted in the "observations" above. Given the relatively "flat" organizational structure that has been developed, attention to interface management will ensure coherent program planning and execution, and will prevent the development of independent constituencies.

III. Budget Overview and Status

We reviewed the FY2017 budget request. The budget numbers did not reflect the recent reorganization and we request that future budget presentations map the new organizational structure and provide budget breakdowns by office.

IV. Modeling and Simulation of Fuels

Summary

The Subcommittee was briefed by Dr. Steven L. Hayes, Technical Lead for the NEAMS Fuels Product Line and Focus Area Lead for Advanced Reactors Fuel Development. Dr. Hayes presented a results-oriented talk that highlighted recent developments of the BISON code and its application to a broad range of nuclear fuel problems.

The MOOSE-BISON-MARMOT (MBM) code suite provides the reactor fuels analysis and development community an advanced computational toolset that includes three key elements: MARMOT, a mesoscale materials model that can be informed by atomistic methods to simulate the evolution of microstructure in nuclear fuels under irradiation; BISON, an engineering-scale fuel design and performance tool allowing analysis under steady-state and transient conditions in a reactor; and MOOSE, an object-oriented simulation framework for the foregoing computational modules and supporting finite-element based applications. The so-called "MBM" toolset is a major product of the NEAMS campaign.

Dr. Hayes' presentation focused on analytical fuels work completed using the BISON 1.3 code, released on 9/30/16. In addition to describing its overall capabilities, Dr. Hayes focused on key example applications that addressed analytical and fuel development issues across both light-water and advanced reactor categories. The recent BISON Assessment Report reflects a continually expanding database of simulation comparisons to LWR fuel rod experimental data, as well as a growing set of benchmark problems with TRISO fuel. BISON usage is impressive, extending now to six DOE National Laboratories and including the university, industry, and international communities. Notable examples include collaborations with the OECD Halden Reactor Project (Norway), the UK's National Nuclear Laboratory, and the IAEA (Fuel Modeling in Accident Conditions, aka FUMAC).

An extensive study of fuel defects focused on the 3D effect of Missing Pellet Surfaces (MPS), which can have significant consequences resulting from hour-glassing of fuel pellets in response to thermal stresses. Efficient high-fidelity modeling of such local effects challenges the transfer of boundary conditions between 3D local sub-models and global, full fuel-rod models in 2D. Cladding temperatures beyond the sub-model regions and relative motion between fuel and cladding are key performance measures. The BISON code is being used to design a special series of 3D experiments to be conducted at the Halden Reactor Project to highlight fuel thermal and mechanical behavior in response to Missing Pellet Surfaces at selected locations of the fuel rod. It is expected that, following a two-year irradiation, these experiments should produce a useful set of validation data.

Another high-impact, multi-year problem being tackled involves the predictive modeling and simulation of proposed new cladding materials (e.g., FeCrAl) and fuel forms (e.g., uranium silicide) in the Accident Tolerant Fuels program. Fuel performance studies will analyze effects on ductility, thermal conductivity, swelling, and fission gas release under a wide range of operating conditions, from normal operations to accident conditions (e.g., TMI-like LOCA, and Fukushima-like Station Blackout).

BISON is also being used in the design of advanced reactor fuels (e.g., metallic and MOX fuels in Sodium Fast Reactors). The Advanced Fuels Campaign is a major user of the BISON computational capabilities. Simulations will be used to design irradiation experiments at the Advanced Test Reactor (ATR), as well as to guide the analysis of planned Post-Irradiation Examinations (PIE). Phenomenology associated with voids at the fuel-cladding interface, as well as the onset of fuel-cladding chemical interactions, will be studied. The use of BISON to design and analyze fuels for especially high burnup in fast reactors (e.g., TerraPower design) will enable the development of such reactors with proliferation-resistant and efficient actinide-burning features.

Finally, BISON is being used to address problems associated with Used Fuel Disposition (UFD). In this case, LWR fuels are modeled from multi-year irradiation in a PWR, through spent-fuel pool storage for 10 years, through the vacuum drying process, to ultimate dry storage in fuel casks. Thermo-mechanical response in fuel and cladding materials will be simulated using multi-scale methods interfacing MARMOT and BISON codes. Key phenomena of interest include: hydrogen diffusion and uptake, hydride formation, material creep, as well as convective and radiative heat transfer under storage conditions.

A multi-year program of major NEAMS-Fuel Product Line milestones covering FY17 through FY22 was also presented.

The MBM computational capabilities will offer state-of-the-art modeling and simulation tools for a broad user and regulatory community under the auspices of the announced Gateway for Accelerated Innovation in Nuclear (GAIN) initiative.

Noteworthy Observations and Highlights

- The NEAMS fuel modeling and simulation codes are significantly expanding their user base, to include National Laboratories, universities, and industry. Collaborations are being fostered with key international entities.
- A very healthy emphasis is being placed on the importance of experimental validation of simulation results, using both archival and prospective experimental datasets. The periodic BISON Assessment Reports are noteworthy in this regard, illustrating the variety and depth of referenced experimental data covering fuel temperatures, fission gas release, cladding profilometry and elongation (among others). Interfacing with the regulatory community via

comparisons to FRAPCON/FRAPTRAN results will build very important credibility in that community.

- The program is focusing on relevant problems for the community, covering all major NE programs and supporting all major fuel design and development, accident tolerant fuel forms, metallic and TRISO fuel forms, and lifecycle fuel behavior associated with Used Fuel Disposition.
- Involvement of NEAMS in the GAIN initiative is laudable and highly encouraged. In addition to growing a wider user base, the program will reap the rewards of ever-expanding experimental validation data and the training and development of a more technically-capable and informed "next generation" of nuclear reactor and fuel designers/analysts.

Recommendations

- Extend demonstration of the value of multi-scale simulation of nuclear fuel performance by interfacing MARMOT and BISON on a more regular basis and among a more diverse user base. Larger numbers of examples explicitly illustrating higher-fidelity modeling with improved meso-scale models would be useful in demonstrating transformational impact on NE programmatic objectives.
- Likewise, there is considerable value in also linking BISON with thermal-hydraulic and thermo-mechanical codes (also developed under the NEAMS framework and demonstrated in the CASL technical effort). Such interfacing would extend high-fidelity simulation to improved modeling of full core behavior, as influenced by the introduction of new, innovative fuels.
- Error bars were noticeably *absent* from the results presented. This highlights a continued need for uncertainty analysis in simulations and full comparisons to experimental data (also with associated error bars). This will be critical for reaping the ultimate rewards for "predictive simulation" over and above those for capacity computing in the future.
- We recommend future emphasis on benchmarking with "similar" foreign codes in the context of international studies (possibly in collaboration with NEA or IAEA); for instance, national safety and regulatory commissions are considering joint international comparative studies when considering the safety aspects of innovative fuels that still lack extensive irradiation histories. Sharing common results would offer reciprocal value in such efforts.
- As the possibility of a new "Test Reactor" becomes a more likely prospect, the MBM simulation capability should be harnessed in setting the goals and objectives of such new capability (including instrumentation), based on the strategic design of an experimental program that would advance the commercialization timeline for next-generation and advanced reactors.
- U.S. leadership in nuclear energy technology hinges significantly on making more rapid progress in deployment of nuclear energy in the U.S. and around the world to arrest the impacts of global climate change (2030 timeframe). Arguably the nuclear community faces an existential challenge in this regard. In resonance with the ANS President's call for a set of "Grand Challenges", the NEAMS-Fuels Product Line, working in collaboration with other elements of NE, should formulate a suitable "Grand Challenge" that would result in a transformational impact on reactor deployment timelines. Thought should be given to the challenge of "Predictive Nuclear Fuels Qualification" (including ATF) that would engage modern simulation capability with the

fuel development effort to significantly lower the scope and cost of necessary fuel irradiation testing to positively impact the reactor development and regulatory timeline. Fleshing out such an initiative would force major attention to uncertainty quantification, acceptable operational performance margins, and instrumentation and scoping of future test and irradiation reactors/facilities. Linking such an effort to reduce the timeline required to impact global warming would provide a superb example of the transformational impact provided by advanced simulation to help advance the clean-energy promise of nuclear technology.

V. Materials and Chemical Technologies (NE-43) Direction & Strategy

The reorganization of the Office of Nuclear Energy now incorporates in the same office Advanced Reactor technologies, Advanced Fuel technologies, and Materials and Chemical technologies, which appear to the Subcommittee as a coherent move to a better integration of these research activities in support of future nuclear systems. NE-43 is now titled the "Office of Materials and Chemical Technologies", addressing issues in Materials Recovery and Waste Form Development (MRWFD), Fuel Resources, Material Protection Accounting and Control (MPACT), and a new scope in Materials Science. Systems Analysis, which conducted the Nuclear Fuel Cycle Evaluation and Screening Study, now resides in NE-42. In addition, this office is also home to the joint fuel cycle study with the Republic of Korea, although this program remains largely independent.

Within NE-43, the MRWFD campaign encompasses development of aqueous separation methods, technologies for TRU recovery and recycles, approaches to off-gas treatment, development of advanced waste forms, and electrochemical processing methods for recycle of fast reactor fuel. The very comprehensive Nuclear Fuel Cycle Evaluation and Screening Study has clearly indicated that continuous recycle of U/Pu or U/TRU are the most promising sustainable fuel cycles, with benefits for minimizing waste disposal namely by reduced heat load. The Subcommittee appreciates that the NE-43 Office is now more clearly aligning program priorities on the implementation of these fuel cycle options as defined in the Evaluation & Screening study. In addition, the program seeks to maintain knowledge and capability in the areas of materials and separation chemistry. This is a challenge, given recent budget constraints.

In the face of a ~50% budget reduction over the past 5-6 years, NE-43 has sought leverage to keep some efforts going. Compared to the multi-step complex separation process, lab-scale demonstration carried out in the last few years, the research objectives of the Sigma Team for Advanced Actinide Recovery are now focused on simpler and more robust methods based on one or two primary approaches for which deployment should be more cost effective and completed within a shorter time period, based on their TRL assessment. Other areas have been reduced, such as the off-gas capture efforts which will now be the subject of a NEUP call. Advanced waste form development and characterization work (including efforts in glass corrosion) may take place under the context of an integrated research project. The Subcommittee acknowledges the effective optimization of the budget of the MRWFD campaign, but still recommends maintaining at least the FY16 level of commitment in the future after the past year reduction. It will be challenging to serve the interests of a 2020 goal presented by DOE for initiating design of a pilot plant for LWR fuel recycling, while also keeping open multiple options (e.g., advanced aqueous recycle and pyro-processing).

MRWFD joint modeling and simulation work with the MPACT campaign was highlighted as another opportunity for improved use of budget funding, to be evaluated at a joint workshop planned for January of 2017. Other efforts appear to be nearing fruition: for example, the Fuel Resources program has made significant progress in improving the capacity, selectivity, and durability of materials for uranium sorption, while reducing the cost of the technology.

The objectives of the co-decontamination project CoDCon were also presented to the Subcommittee; CoDCon (~1kg demonstration of a separation process to generate 70/30 U:Pu MOX feed material) is of interest to both the MRWFD and MPACT campaigns, serving to evaluate both process control and material accountability. For example, the capability for the co-conversion step of the U/Pu nitrate stream from the solvent extraction to a mixed powder material suitable for pellet fabrication has to be demonstrated while determining the uncertainty of maintaining the 70/30 target throughout the process. Some aspects of the integrated timeline of CoDCon are not clear and possibly too optimistic: can Phase 1 (glovebox testing) and Phase 2 (hot cell testing) both be accomplished in the FY18-19 timeframe to serve the 2020 long-term milestone? The Subcommittee would like to hear more about progress on this demonstration.

NE-43 incorporates the new "Materials" campaign, for which the formulation phase was presented to the Subcommittee. While work in materials research has been coordinated both within NE (NEET-RM, SBIR components) and with other parts of the Department (e.g., SC-BES), there is a broad spectrum of needs. Some of the topics identified in the presentation included radiation and corrosion effects, as well as determining thermo-physical property data for molten salt systems. Time did not prove adequate to probe the coordination between these efforts and materials modeling and simulation work within NE-5. The Subcommittee recommends development of a description of the scope of this campaign, and a roadmap for priorities based on key long-term milestones, taking into account coordination with other NE efforts (including engaging university programs when feasible).

VI. Advanced Reactor Technology Program (NE-41)

The Advanced Reactor Technology (ART) Program has the overarching mission of performing R&D aimed at reducing technical risk, enhancing safety and security, and improving economic competitiveness of advanced reactors as a resource capable of meeting the Nation's energy, environmental, and national security needs. Research encompassed within this program includes topics related to: fast reactor technologies (which offer benefits related to fuel cycle management), high temperature reactor technologies, including proposed gas- and liquid salt-cooled systems (which offer benefits related to reactor siting and high temperature applications), *generic* advanced reactor technologies (common needs by multiple technologies, including supercritical CO_2 Brayton Cycles), advanced reactor system studies (including planning for advanced test or demonstration reactors), and new reactor technologies for space and special purpose applications. The program has defined *success* as having technical challenges "sufficiently resolved to enable transition of advanced non-LWR reactor technologies and systems to commercialization, regulatory review and deployment by the early 2030's". However, the program currently relies on funding decisions made assuming the former DOE-NE organization.

Our Subcommittee recommends that this program implement reorganization-based changes. We see the following recommendations and comments essential for successful implementation of this program within the new DOE-NE organizational structure:

- This program recognizes several important strategic DOE-NE interfaces such as industry-led Advanced Reactor Concept projects, the GAIN initiative, and relevant NEI, NNSA, NASA, and international programs. However, the Subcommittee observes the ART is implicitly relying on other interfaces within DOE-NE, such as the NEET, NEAMS, NEUP, and IRP efforts. ***This reliance should be explicitly noted on organizational charges and the mechanisms used to ensure that the cross-cutting areas consider ART input should be explicitly identified.***
- The program has linked success with a timeframe (i.e., the early 2030's). At this time, government funding is too limited (even with an optimistic scenario) to deploy all the technologies currently under investigation within this timeframe. ***We STRONGLY recommend that research (and associated funding allocations) be prioritized based on a DOE strategy that considers technology readiness so that SOME technologies are ready for deployment within this timeframe.***
- Given the multiple influences and players in the Department's decision-making structure for the selection and ultimate deployment of new reactor technologies, it was unclear to the Subcommittee how this component of the new NE organization is positioned to lead such policy discussions toward ultimate decisions on research investment priorities and new reactor technology deployment. ***DOE should develop a strategy that also addresses this issue.***

VII. Accident Tolerant Fuels

The Subcommittee received an overview and update on the Accident Tolerant Fuels (ATF) program. The program is now structured as an aggressive implementation program with a success-oriented vision. The major goal is to insert a Lead Test Assembly (LTA) or Lead Test Rod (LTR) into a commercial reactor by 2022. Supporting and clarifying this goal, the program has provided a Report to Congress entitled "Development of Light Water Reactor Fuels with Enhanced Accident Tolerance" (June 2015). This report establishes the 2022 insertion date and also clarifies and defines the concept of accident tolerance "as the ability of tolerate loss of active cooling in the core for a considerably longer time than the standard UO_2-Zr fuel system."

The program has broadened its base in the international arena by developing collaborations with France, the European Union, Japan, China, the United Kingdom, the Organization for Economic Cooperation and Development (OECD), and the International Atomic Energy Agency (IAEA).

In addition, the program authorized and completed an Independent Technical Review to rank and prioritize alternative concepts. The result of this ranking was the selection of three vendors (General Electric, AREVA, and Westinghouse) to go forward with the intent of meeting the 2022 insertion goal. As some of the vendors have more than a single concept, the program is going forward with a total of seven concepts. Although the program is currently going forward with these seven concepts, if a vendor cannot make the 2022 date with one or more of their concepts, an automatic down-selection of that or those concepts occurs.

The program has also engaged two utilities (Exelon and Southern Company) as active and aggressive supporters. It is also coordinating with the Nuclear Regulatory Commission (NRC) on possible regulatory approaches or changes related to ATF. In addition to the 2022 insertion goal for a LTA or a LTR, the program has established a second goal for the vendors, which is to develop a licensing plan in coordination with a utility, to support the 2022 insertion goal and to do so within two years. Both the 2022 insertion goal and the two-year licensing plan goal are quite aggressive and success oriented. The Subcommittee is impressed with the organization, aggressive implementation, and success-oriented nature of the ATF program with the intent and focus on completing the mission of developing an ATF.

VIII. Cladding for Fast Reactor Fuels

The Subcommittee received a presentation on the program to develop cladding for fast reactor fuels. The program is part of the effort managed by the Office of Advanced Fuels Technologies within NTRD. The Technical Lead for the fast reactor cladding part of this program is Dr. Stuart Maloy, who is located at the Los Alamos National Laboratory (LANL).

To the credit of the Technical Lead, the program has established an impressive and comprehensive set of participating organizations. Among these are both national laboratories and universities, so the program draws upon the most effective scientific talent and associated equipment regardless of where it may be located. This includes not only LANL, but Oak Ridge National Laboratory (ORNL), the Pacific Northwest National Laboratory (PNNL), the University of California at Santa Barbara (UCSB), Case Western Reserve University (CWRU), Texas A&M University, the University of California at Berkeley (UCB), as well as an international participant in the Kharkov Institute of Physics and Technology (Ukraine).

The mission of the program is to develop and demonstrate fabrication processes and in-reactor performance for advanced fuels and targets (including cladding) to support different fuel cycle options as defined in the “Nuclear Energy Research and Development Roadmap – A Report to Congress” (April 2010). An essential goal to achieve this is to develop advanced radiation tolerant materials capable of performing their function under irradiation to a very large number of displacements per atom (dpa).

Within the program to develop fast reactor cladding, there are two goals which would be important to reactor designers and which would allow them to design to higher burnup. These goals are to obtain radiation dose data on the alloy HT-9 at more than 250 dpa, and also to develop fabrication processes for Oxide Dispersion Strengthened (ODS) alloys such as 14YWT

A key element of this program is to take the low-swelling ferritic-martensitic HT-9 alloy irradiated as coupons and pressurized capsules in the Material Open Test Assembly (MOTA) in the Fast Flux Test Facility (FFTF) and extend their irradiation, or increase their dpa, by irradiating them further in the Russian reactor BOR-60 or possibly in the Chinese Experimental Fast Reactor (CEFR). This novel approach builds upon the irradiation data available to date and accelerates the acquisition of higher dpa data.

An additional element of this program is to cut samples from an HT-9 duct irradiated in the ACO-3 duct test in FFTF and subject them to mechanical testing to determine mechanical properties such as the yield point, maximum tensile stress, ductility, high-temperature fracture toughness, and low-temperature hardening at various temperatures and dpa.

Both of the above activities, including the subsequent irradiation of MOTA coupons in BOR-60 and testing of samples cut from the ACO-3 duct, illustrate the advantages of the comprehensive and collaborative program structure as the coupons and the duct were provided by PNNL and were analyzed by almost all of the program participants.

The program has also successfully developed a process for fabricating 14YWT beginning with powder and ending with metal billets with the intent to then develop a fabrication process for this alloy leading tubing which would then be subject to in-reactor irradiations. 14YWT is an Oxide Dispersion Strengthened (ODS) nano-structured ferritic alloy with the potential to go to even longer irradiations and higher dpa than HT-9.

Given the absence of a domestic test reactor and recognizing the difficultly of testing in foreign reactors, the program is investigating ion irradiation using accelerators to produce high dpa irradiations. The goal of these irradiations is to determine when break-away swelling occurs, i.e., when an alloy exhibiting a low swelling rate transitions to a much larger swelling rate. This will be challenging because both the damage mechanism and damage rate for charged particles is different than that for neutrons.

The Subcommittee commends the program manager on developing a comprehensive far-reaching program using multiple participants. We close with the following observation and a recommendation:

- The properties being developed for the advanced alloys as a function of their irradiated dpa are not only very useful to reactor designers, but also essential to developing a good design.
- Therefore the Subcommittee recommends that the program develop a set of tables identifying data available for each alloy under development.
    - The tables would indicate what data and material properties are available now and likewise provide as estimate of when future materials data might be available if they are not available already.
    - Such tables would allow a reactor designer to choose which materials to include in his/her design in its initial stages and allow him/her to determine when he might be able to upgrade his/her design to higher performance levels when new material data is available.

IX. Material Protection and Control (MPACT)

Summary

The Subcommittee was briefed by Dr. Michael Miller, National Technical Director for the Materials Protection, Accounting and Control Technologies (MPACT) program element. Dr. Miller presented a number of research highlights in his talk, as well as motivation for the formulation of a new 2020 Program Milestone. The stated objectives of the MPACT initiative include: development of technologies to “fill important gaps”; application of developed tools to support assessments on advanced fuel cycle concepts; and development of guidelines for applying “safeguards and security by design” to new facility concepts.

R&D highlights were presented in three general categories: (1) technology development for electrochemical fuel cycle processing; (2) development of advanced instrumentation to support “next generation” nuclear materials management; (3) preparatory work toward an “Advanced Integration” capability linking sensor technologies, modeling and simulation, and advanced data management and analysis.

Electrochemical process monitoring technologies included: actinide sensors employing a potentiometric sensor fielded in a multicomponent molten salt; level/density sensors adapting bubblers for molten salt environments; microfluidic sampling technology to enable high-throughput automation; and voltammetric sensing for *in-situ* monitoring of actinide concentrations.

In the exploratory research (advanced instrumentation) area, overviews were given on micro-calorimetric instruments for very high resolution gamma spectrometry, as well as novel neutron detection for high gamma environments and real-time, in-process plutonium concentration measurements in U/TRU alloys.

Finally, an Advanced Integration Milestone (2020) was presented as a proposed lab-scale demonstration of an advanced safeguards and security system. The notional concept involves characterization of safeguards and security performance in a “virtual facility” through the integration of real (existing) data and “synthetic data” enabled by modeling and simulation of facility processes. The transformational effect of such capability will be attained by employing data fusion techniques to integrate disparate data sets, as well as by employing pattern recognition, uncertainty quantification, and statistical inference to perform the requisite analyses.

Highlights and Observations

- Given the interest in Molten Salt Reactor concepts and proposed electrochemical used-fuel processing approaches, emphasis on developing monitoring technology for in-process bulk flows appears to be consistent with broader NE and nuclear industry priorities, and takes advantage of a significant associated facility and operational knowledge base. These priorities are also aligned with the Joint Fuel Cycle Study.
- A “systems approach” is consistently referenced in the MPACT program element. This is obligatory in the context of “Safeguards by Design” and “Next Generation Safeguards”, but needs to be reflected also in coherently-executed technical strategy.
- However, the program still gives the impression of a collection of projects with no unifying theme or strategy, i.e., much of the research appears open-ended with no near-term objective or ultimate goal in mind. There is a prevailing sense of “level of effort”, rather than goal-driven approach.

- Whereas the individual MPACT projects appear to be well managed, we did not see a cohesive requirements-driven management approach across the overall MPACT program that also reflects a coordinated strategy with NNSA (and perhaps also the State Department).
- A coherent strategic framework for the technology development is not evident, in the sense of a cascading set of technical requirements that derive from high-level, but nevertheless ***concrete***, domestic and international safeguards and security objectives. There is too much of a gap between aspirational goals and specific technology development outcomes.

Recommendations

- Recognizing that the budget is relatively small, the Subcommittee still believes that a long-term planning exercise undertaken by the program managers could provide substantial benefits. Such a planning exercise should develop discrete objectives across the various research areas and would help channel open-ended research projects toward achievable near-term milestones and eventual endpoints.
- Given the extent to which MPACT may be influenced by U.S. nonproliferation and national security policy, as well as global IAEA safeguards requirements and implementation timelines, a joint strategic planning exercise with NNSA and appropriate State Department offices would seem to be in order. A "level of effort" program in the context of a rapidly evolving policy environment (e.g., change of Administrations and pressures on the Federal budget) could face substantial budget risk unless bolstered by an overarching and compelling strategy.
- As planning evolves with respect to Advanced Reactor Technology and used fuel disposition/advanced fuel cycle options, NE should take the government lead in adapting and converting aspirational Gen IV objectives regarding lower proliferation risk to technical criteria that could be used to concretely guide technology development. The "Safeguards by Design" program has been embraced by both NNSA and NE; however, tangible technical results have yet to be applied to reactor and fuel cycle designs in the developmental pipeline. The Gen IV International Forum has embraced a methodical approach to quantifying "Proliferation Resistance/Physical Protection (PR/PP)". Several in-depth assessments have been published already. Use of this methodology to inform the design of nuclear energy systems of the future by proposing design criteria and associated implementation costs would go a long way toward providing a coherent strategic direction to this program.

X. INL Irradiation Testing & Capabilities Update (TREAT)

TREAT Restart and Transient Testing Program

Efforts to restart the Transient Reactor Test Facility (TREAT) at the Idaho National Laboratory continue. This facility, which started operation in 1959, was placed in 'standby' in 1994. TREAT was built to conduct transient reactor tests in which fuels and materials are subjected to neutron pulses that can simulate conditions ranging from mild upsets to severe reactor accidents. The reactor was constructed to test fast reactor fuels, but has also been used for testing for light water reactors as well as other special application reactors (e.g., space reactors). The TREAT facility is unique because of its large test volumes that allow evaluation of multi-pin response to a reactivity insertion accident (RIA).

During our meeting, the Subcommittee heard that the TREAT restart schedule was currently driven by the need to support the DOE-NE Accident Tolerant Fuel (ATF) program, which requires TREAT to be ready for testing by the end of 2018. Currently, this restart effort is going faster than anticipated, and there is the possibility for TREAT to be restarted as soon as March, 2018.

We also learned of efforts by INL to develop a testing program to support domestic and international customers. The first anticipated customer, the ATF program, has sponsored the design of an instrumented test vehicle to support RIA testing. Refurbishment of the hodoscope for TREAT is funded by the NSUF, and instrumentation to support TREAT testing is being developed using university IRP and NEUP funding. Several international agreements have been modified to include TREAT testing as an area of collaboration, but such activities will require funding from other DOE-NE programs.

During this briefing, the Subcommittee learned that the annual TREAT operational budget is expected to run between $20 and $25 M. However, funding allocations are currently limited to $75 M for TREAT restart. The TREAT restart budget doesn't include *any* development of infrastructure to support user testing, such as standardized instrumented test rigs or loops that would enable TREAT to economically meet user needs. It is currently estimated that development of *each* test loop would cost around $10 M.

In reviewing the status of the TREAT restart effort, the Subcommittee emphasizes the need for the U.S. to fund TREAT facility operations and infrastructure to support a transient test program. ***Funding is required to develop test loops and instrumented test rigs to meet anticipated user needs. If DOE-NE doesn't explicitly identify or request such funding, we fear that the facility will not attract and maintain an adequate customer base to support its use.***