Report to NEAC

Nuclear Technology R&D Subcommittee

Meeting of December 11, 2017

Washington, DC

March 23, 2018

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I. Introduction

The agenda for the December 11, 2017 Nuclear Technology R&D Subcommittee meeting is shown 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 Office (NE-4), and related research that is coordinated with NE-4. All members of the Subcommittee were present.

Agenda

Chair: Dr. Alfred P. Sattelberger
Location: Argonne National Laboratory, L'Enfant Conference Room B15 – 6th Floor

8:30	Arrive Argonne Office and Sign-In
8:45–9:15	Executive Committee – Closed Session
9:15–9:30	Budget Update
9:30-10:15	Accident Tolerant Fuel – Vendor/Utility/NRC Update
10:15	Break
10:30-12:00	Versatile Test Reactor R&D Overview
12:00–1:00	Lunch
1:00–1:45	Portable Micro Reactor concept for remote applications
1:45-2:15	MPACT Programmatic Direction & Coordination w/NNSA – Including Joint Fuel Cycle
2:15–2:45	Glass Waste Forms – NWTRB Recommendations
2:45	Break
3:00–3:30	Advanced Reactor Technologies Program – Update
3:30–4:15	TREAT Start-up Update
4:15–5:30	Closed Session
5:30	Adjourn

As usual, our report is organized along the lines of the agenda.

II. Budget Update

Bob Rova reviewed the current NE-4 FY17 and FY18 CR budget and noted that the activities in Used Nuclear Fuel Disposal R&D (UNFDRD) and Integrated Waste Management Systems (IWMS) were discontinued. Interim storage and transportation planning scope is being moved under the new Yucca Mountain (YM) and Interim Storage Programs, which plan to restart licensing activities for the YM nuclear waste repository and to initiate a robust interim storage program.

III. Accident Tolerant Fuel – Vendor/Utility/NRC Update

Analysis of Efforts to Support Accident Tolerant Fuel Program

The Subcommittee continues to monitor progress of the Accident Tolerant Fuel (ATF) program, which has been tasked by Congress to pursue the development and qualification of accident tolerant nuclear fuels that would enhance the safety of present and future generation Light Water Reactors (LWRs). Increased safety associated with ATF concepts rely on their ability to significantly extend the time before initiation of the exothermic oxidation reaction associated with hydrogen generation from the zircaloy-based cladding in current LWR fuel. Although other ATF concepts such as Silicon-Carbide (SiC) clad fuel are under development, the ATF program is currently focused on the designs listed in Table 1 and their near-term irradiations of Lead Test Rods (LTRs) and/or Lead Test Assemblies (LTAs) in commercial reactors.

Table 1: Near-term Accident Tolerant Fuel LTR/LTA Irradiations

Vendor	Fuel Description	Proposed LTR/LTA Irradiation	
		Date	Plant
GE	Iron-Chromium-Aluminum (FeCrAl) Alloy Cladding on Uranium Dioxide (UO_2) Fuel	Spring 2018	Hatch Unit 1 BWR
AREVA	Chromium-Coated M5® Cladding on Chromia-doped UO_2 Fuel	Spring 2019	Vogtle Unit 2 PWR
Westinghouse	Chromium-coated Zirlo Cladding on Uranium Disilicide (U_3Si_2) Fuel (EnCore™)	Spring 2019	Byron Unit 2 PWR

Because the Technology Readiness Level (TRL) differs for the fuels listed in Table 1, the qualification approach proposed by each vendor varies. For example, GE plans to irradiate several LTAs containing several distinct types of LTRs to investigate different FeCrAl alloys and different UO_2-based fuels. AREVA plans to irradiate four full LTAs of their enhanced fuel. Westinghouse plans to start by irradiating LTRs of their EnCore Fuel by Spring 2019 and have LTAs ready for irradiation in PWRs by Spring 2021. Ultimately, all three vendors will need to qualify the fuels for high burnups (e.g., greater than 62 GWD/MtU). To support ATF design, qualification, and commercialization activities, industry has formed a working group to address regulatory and economic issues. In 2017, DOE signed a Memo of Understanding (MOU) with the U.S. Nuclear Regulatory Commission (NRC) to identify what experimental data are required to address safety issues associated with ATF concepts and how to expedite ATF licensing reviews.

DOE provides significant resources to support ATF deployment, including fabrication of some fuel pellet and coated clad variants; irradiation testing of fuel exposed to nominal PWR and BWR conditions in the ATR (INL) and the HBWR (Halden); and transient fuel testing at TREAT (INL). In addition, DOE has developed infrastructure to support Loss of Coolant Accident (LOCA) testing of irradiated fuel at ORNL and irradiated fuel material characterization and thermal property testing at INL. Furthermore, DOE experts have developed Fuel System Handbooks to collect and disseminate the state-of-knowledge regarding the ATF fuel and cladding systems. DOE ATF efforts are guided by a Roadmap, which is currently being updated to reflect current test plans and to better define roles and responsibilities using guidance issued by the new Administration.

Observations and Recommendations

As previously noted, the ATF designs are at different TRLs with differences in the amount of time and funding levels required for their ultimate commercialization. The Subcommittee recommends that ATF research activities be prioritized by considering TRL levels. This prioritization could be implemented as part of on-going Roadmap Update efforts (e.g., include a task to document the TRL of each fuel concept and the timing and amount of funding required for their qualification, deployment, and commercialization). The Subcommittee suggests that the Roadmap explicitly address the fabrication maturation steps from DOE laboratory bench scales through industrial pilot line deployment to scaled industrial deployment. Licensing will require some key data be demonstrated by fuel qualification irradiations of rods fabricated by scaled, deployed systems rather than by bench-scale samples.

As previously noted, DOE signed a MOU with NRC in 2017. To increase regulatory efficiency, the Subcommittee urges DOE to have NRC participate in the detailed planning of near-term irradiation tests to ensure that required data needs are identified and appropriate tests with approved methods are performed to address these data needs. Early NRC input regarding the information needed to license ATF concepts could significantly reduce testing costs and expedite regulatory reviews.

In prior reviews, the Subcommittee emphasized the need to provide analyses that demonstrate the safety benefit of ATF concepts during severe accidents using systems analysis codes, such as MELCOR and MAAP. Our evaluation indicated that new data are required to characterize thermal and structural properties of new ATF materials and, in some cases, new models may be needed to characterize ATF performance during beyond design basis or 'severe accident' conditions. We continue to emphasize these points and recommend that this effort be coordinated with other on-going efforts by DOE's Light Water Reactor Sustainability Reactor Safety Technologies (LWRS RST) program and EPRI to obtain insights about the accident tolerance of the plant, i.e., evaluations should consider all plant systems and components, including new FLEX equipment, that could mitigate risk-important severe accidents.

During our December 2017 review, we learned of on-going efforts by industry to develop a business case for ATF concepts. In addition to anticipated economic performance-based benefits of the ATF concepts, plant economic benefits may also accrue if requirements for some safety-related plant equipment are relaxed due to enhanced accident tolerance benefits of ATF concepts -- not a required commercialization criterion, but certainly desirable if effected. The Subcommittee emphasizes that higher fidelity systems analyses evaluations will be required to support such a business case and recommends that regulatory input be obtained to understand the type and cost of data required to support such relaxations of regulatory requirements.

The Subcommittee recommends that efforts to develop this business case be expedited to provide confidence that ATF efforts will yield a product that can be commercialized.

IV. Versatile Test Reactor R&D Overview

The Subcommittee received an overview presentation on the program to develop a Versatile Test Reactor (VTR). The Subcommittee has a number of observations and recommendations based on the presentation, the discussion during the presentation, and questions and answers. A decision has been made to conduct the initial phase of the design of a VTR as an R&D program in order to resolve some outstanding R&D questions. Once this is completed, the plan is to engage in a DOE Order 413.3B project at an appropriate later time. With this in mind, the Subcommittee has a number of observations and recommendations related to completing the R&D phase.

- **Closed Loops:** The installation and simultaneous operation of multiple Closed Loop Systems (CLSs) representative of typical fast reactor coolants (i.e., sodium, lead, lead-bismuth eutectic, gas, and molten salt) are being considered. It would be useful to keep in mind that a CLS are complicated; each CLS requires its own primary coolant loop, possibly an intermediate coolant loop, a heat rejection system, an instrumentation and control system, and its own control station. If the regulatory approach is a DOE Authorization Basis, each CLS will have its own accident initiators and accident propagation mechanisms. Most likely each CLS will contain Safety Class SSCs (i.e., structures, systems, and components), and the performance of these will have to be analyzed and reconciled in the FSAR. This is not to say that a CLS is not an important part of a test reactor, quite the contrary; rather it is to emphasize that a CLS has design, regulatory, and operating complications. It may be important to minimize the number of CLSs to be consistent with well-defined R&D needs.

The Subcommittee suggests that two specific CLS-related topics be considered:

1) A single, central CLS is likely to provide maximum flux relative to a distributed set of in-core loops. The higher experimental throughput that such a higher flux loop could support - in terms of fuel burnup and material damage - would mitigate the loss of parallel experiments at lower flux levels. “Peripheral” loop positions with lower flux levels could be of high value for lower-technical-maturity irradiations or for power application prototypic irradiations. Metrics for experimental flexibility and throughput should be developed early in the design phase to facilitate comparison of the benefits of CLS configurations versus the costs of complexities associated with multiple CLS configurations.

2) The use of an instrumented Standardized Device Paradigm (similar to the TREAT loop concept) or a Closed Loop In-Reactor Assembly (CLIRA as was used in FFTF) should be pursued to allow the loops to be highly configurable as user facilities. Such an approach could allow the many types of reactor classes and concepts to be tested by a smaller set of CLS positions in the core and eliminate the need for one-of-a-kind designs that must be developed for each irradiation. Users and the regulators, as well as experts from international irradiation facilities, should be contacted to ensure that instrumentation required to support user irradiations is available and can be accommodated in these standardized test devices.

- **Thermal Spectrum:** The possibility of including an irradiation location with a thermal spectrum is being considered in developing the VTR design. This may not be as important as the ability to retrofit a thermal spectrum region later, consistent with the experimenter’s needs. As an example, the FFTF (Fast Flux Test Facility) was able to retrofit thermal regions using yttrium- hydride moderator pins to construct and tailor a local thermal spectrum consistent with experimenter needs.

- **Evolving R&D Missions:** Meeting all the mission requirements with the first core may not be as important as the ability to evolve toward them. For example, achieving a fast flux of 5×10^{15} n/cm^2-

sec (>100 Kev) in the first core may not be as important as a plan to increase localized fast flux as experience with testing is obtained.

- **Evolutionary Fuel Approach:** The different maturity level of fuels under consideration, coupled with little reactor-grade plutonium available in the U.S. suggests that a startup with U-10ZR fuel followed by transition to U-27PU-10Zr may be advantageous. Such an approach would likely result in a core design that evolves from a larger initial core radius to a more compact equilibrium core radius. That would imply additional peripheral experimental volume available for the equilibrium core, perhaps accommodating peripheral CLS positions.

- **Beneficial Waste Heat Utilization:** Current plans are to not produce electrical power but to use air-blast dump heat exchangers as the heat sink. This is identical to the approach taken at FFTF and is a well-known technology. Nonetheless, it may be worthwhile to consider possible beneficial uses of the waste heat. For example, the most effective design of a steam generator is a problem that has evaded designers of SFR (sodium fast reactors) for decades. Assuming that the heat sink for the VTR would be similar to that of FFTF, i.e., multiple loops each with a 33 MWt dump heat exchanger, the possibility of using one or more of these loops to test a heat exchanger may be worth considering.

- **Fuel Length Effect:** Several designers of SFR have articulated a desire for a test reactor capable of testing fuel with at least a meter of active fuel length. This desire is based on the fact that there is a length effect associated with migration of various fission products within the fuel pin either by concentration gradients or by thermal diffusion. It is, however, possible to test the length effect phenomena by creating a chopped cosine power distribution, which will allow fission products to diffuse in accordance with concentration and thermal gradients. This will allow the phenomena to be tested without necessarily being prototypic of any one designer's specific length or height.

- **Transitioning to Design/Build:** The current organization chart for the VTR is an R&D organization chart. Given that the plan is to ultimately develop a DOE 413.3B project, it may be worthwhile giving some thought to what a Design/Build organization chart might look like and how the transition to same might be made.

- **Maintaining R&D Capability:** As it is unlikely that all R&D questions will be closed when the transition to a DOE 413.3B project occurs, it may very well be important to maintain an R&D support capability to resolve open R&D questions as they occur during the 413.3B project. Those R&D areas needing continuing support will become evident as the transition to a 413.3B project nears.

V. Portable Micro Reactor Concept for Remote Applications

Kemal Pasamehmetoglu informed the Subcommittee of a LANL-INL LDRD-funded design effort for a very small modular reactor (vSMR). This design effort is illustrative of a class of vSMR concepts also being developed by industry, which enjoy many common aspects of transportability, safety, flexibility and manufacturability, but which differ in unique technologies being adopted for their commercial designs. NE-41 added a new reactor technology R&D portfolio, called Special Purpose Applications, to address cross-cutting R&D needs for development and commercialization of vSMRs. These low power reactors answer the need for deployable nuclear power sources (not dependent on indigenous fuel availability or reliant on vulnerable fuel supply chains) that can be integrated into very small electrical grids, including those in military bases around the world or in very remote locations. Requirements for such reactors include: amenability to rapid deployment, e.g., air-transportability; low, scalable power in the range of 2-10 MWe; capability of operational status within 3 days of arrival and removal within 7 days of shutdown; inherent safety and security; resistance to potential terror threats; allowing easy safeguarding of nuclear materials; ease of operation; and cost-effectiveness. Reactors in this design domain have been nicknamed “micro-reactors” or even “nuclear batteries.”

Reactor concepts in the past have highlighted similar design features with cooling provided by light-water, gas, liquid metals, and heat pipes. For example, the Generation IV International Forum included a proliferation-resistant reactor design involving a lead-cooled fast reactor transportable in a shipping cask. The concept was called SSTAR (for small, sealed, transportable, autonomous reactor). Argonne, Lawrence Livermore, and Los Alamos Laboratories participated in the design and R&D activities. The reactor concept was to provide 10-100 MWe in a package weighing about 500 tons, within a 15 meters x 3 meters cylindrical envelope.

Today’s needs, however, involve a much smaller, lighter package and a much higher Technology Readiness Level. A very workable concept has been developed by Los Alamos National Laboratory (LANL) and is now being jointly developed with Idaho National Laboratory (INL). The design concept involves a heat-pipe cooled reactor offering electrical power in the neighborhood of 2 MWe. Although various core designs are being considered, the general concept involves UO_2 fuel within a steel monolith core and cooled by co-located heat pipes. The design would not involve pumps or valves in the vessel/core area, so could be considered as nearly solid-state. The nuclear package would weigh less than 50 tons and would fill a cylindrical volume 12 ft. long and 6 ft. in diameter. The reactor (within a shipping cask) could be flown and transported by truck to a desired deployment location. Heat pipe thermal output would facilitate easy switch-out to on-site turbine-generators running on a heated air Brayton cycle. The proposed reactors would involve 32% lower fuel cost (compared to diesel power), and would enjoy a 50% footprint advantage over the diesel generators. A 2016 DoD Defense Science Board study looking at energy systems for forward/remote operating bases found the heat-pipe cooled reactor design as one of the two options sufficiently mature to be further evaluated. LANL and INL are now finalizing the design concept and developing an expedited RD&D deployment schedule with anticipated system demonstration of a full-scale reactor prototype at INL in 5 years. In the meantime, the effort plans to simultaneously pursue an NRC construction permit and operating license for the first plant to begin operation at the DOE site and NRC design certification for the concept. In addition, enabled by the GAIN initiative, a MOU is being developed with a private entity (OKLO) to accelerate demonstration and proceed to commercial deployment. This would meet the programmatic objectives of GAIN for enabling faster innovation of nuclear technologies through private-public partnerships. However, we caution that experience has demonstrated that changes to a certified design are expensive and it may be prudent to gain experience from the first operating reactor and implement changes to the design before pursuing certification.

The Subcommittee applauds the joint LANL-INL effort, particularly for pursuing expedited deployment of a new reactor technology. The small, passively safe reactor concept adds substantively to the advanced technology portfolio options being developed across a wide range of power spectrums. The market niche represented by forward-deployed military bases and remote geographical areas offers a smooth way for demonstrating deployment of cost-effective, safe reactors with proliferation resistance to a much expanded base of global customers. In addition to preparing for anticipated regulatory action, the Subcommittee recommends that the design team also complete a quantitative PRPP (Proliferation Resistance and Physical Protection) analysis, perhaps in conjunction with NNSA, on the eventual baseline design to facilitate even broader public acceptance of deployed nuclear energy technology in this important market niche.

VI. MPACT Programmatic Direction & Coordination w/NNSA – Including Joint Fuel Cycle

The Subcommittee heard an update from Dan Vega on the Material Protection, Accounting, and Control Technologies (MPACT) Program. The overall mission of this program continues to be the development of innovative technologies and analysis tools to enable next generation nuclear materials management and security for existing and future U.S. nuclear fuel cycles, minimizing the risk of diversion of material or proliferation of nuclear technology for military application.

The MPACT program has a history of accomplishments in developing instrumentation, modeling and simulation, and engagement with NRC and the international community associated with the design of safeguards in facilities. In general, NE is focused on the development of safeguards methods for domestic civilian facilities, whereas NNSA focuses on traditional safeguards approaches and IAEA support. In practice, there has been benefit in coordination between NE and NNSA; NE provides key expertise and concepts, while NNSA is engaged with international facilities that are appropriate for planning, design, and validation of concepts. Examples include NA-24 cost-sharing for field testing in the development of the Multi-Isotope Process (MIP) monitor, and coordination with NA-22 in advanced instrumentation. Ongoing discussion informs this collaboration, including biannual meetings between Federal program managers to coordinate R&D efforts, and mutual participation in working group discussions.

The enduring objectives for the program include:

- Developing and demonstrating advanced material control and accounting technologies addressing important gaps
- Developing, demonstrating, and applying analysis tools to assess effectiveness and efficiency, guide R&D, and support advanced integration capabilities
- Performing technical assessments in support of advanced fuel cycle concepts and approaches
- Developing guidelines for safeguards and security by design and apply to new facility concepts

As has been described to the Subcommittee in the past, a strategic goal within this effort is to complete lab-scale demonstration of an advanced safeguards and security system by 2020. This system would be founded on high-fidelity tools and physics-based models, integrated into system-level models, with validation based on a set of key metrics describing the characteristics of a facility and probability of various consequences. The choice was made to build this demonstration for a conceptual electrochemical processing facility. Progress has been made; FY17 accomplishments described include improvement in models, adaptation to allow their integration into a virtual facility test bed, and development of analysis and integration capabilities supporting uncertainty quantification and correlation analysis. Notably, an implementation plan was also produced to achieve the 2020 milestone and an update of the Advanced Integration Roadmap. It would be instructive for the Subcommittee to understand the scope of that implementation plan in the future.

Consistent with MPACT's efforts in electrochemical processing, NE has been engaged in the Joint Fuel Cycle Study (JFCS). NE participates in the JFCS Safeguards & Security Working Group. The impact of NE's expertise is clear in the list of MPACT-derived technologies included within the Integrated Recycling Test under the JFCS. FY17 also saw a range of R&D to demonstration efforts associated with advanced instrumentation. Planned activities for FY18 include a similar mix of demonstration and field-testing activities (e.g., field-testing of a high-dose neutron detector, triple bubbler, and Pu concentration measurements, preparation for field testing of micro-calorimeter and voltammetry) and work towards the 2020 strategic milestone (definition of the electrochemical processing flowsheet, models and simulated signatures).

Budgetary limitations appear to be having an impact in MPACT. Exploratory instrumentation projects have been curtailed in the short term, and the three-year (2018-2020) milestone associated with development and testing of integrated approaches for safeguards and security of advanced reactors and other fuel cycle facilities is described “as budget allows”. MPACT clearly makes effective use of opportunities to leverage other investments, including coordination with NNSA and inclusion of a number of NEUP efforts, but budget limitations constrain the important goal of testing integrated approaches in other aspects of advanced reactors and other fuel cycle facilities. Extension of the planned demonstration of an integrated advanced safeguards and security system could have broad impact; the 2020 milestone is fast approaching, and the Subcommittee would like to hear more about the implementation plan.

In the past, the Subcommittee has recommended formulation of a roadmap associated with priority fuel cycle elements and known gaps. We reiterate that such an effort could help ensure that priorities are being identified and defended.

The Subcommittee continues to support the rigorous systems approach that MPACT has followed in approaching the 2020 milestone of completing a lab-scale demonstration of an advanced safeguards and security system. In previous years, the Gen IV Forum and the IAEA [through the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)] have developed quantitative integrated assessment methodologies patterned after traditional Probabilistic Safety Analyses familiar to the nuclear industry. As part of a comprehensive program plan and as the milestone date approaches, it would be very useful to also complete a rigorous PRPP assessment (Proliferation Resistance and Physical Protection) to quantify a facility-level probability of material diversion and to perhaps compare such an analysis to a similar PRPP assessment of a currently operating aqueous-based process. This would be an excellent complement to the development of monitoring, modeling, and analysis tools that have already been integrated into the MPACT program plan and would go a step or two further in developing “actionable” analysis tools to undergird proliferation risk assessments and predictions of breakout times useful to policy analysts and IAEA inspectors.

VII. Glass Waste Forms – NWTRB Recommendations

A presentation from the Materials Recovery and Chemical Technologies office by Patricia Paviet described recent progress in understanding long-term glass corrosion mechanisms that was presented at a Nuclear Waste Technical Review Board (NWTRB) meeting held at PNNL in June 2017. Some of the most promising options for future nuclear energy development involve a closed fuel cycle which will result in the generation of high level waste (HLW) incorporated in various waste forms. There is an acknowledged need within the program to support studies on final durable waste forms obtained by vitrification (considered as the best demonstrated technology) and how these waste forms, such as borosilicate glass, will behave over periods of time up to hundreds of thousands or millions of years.

Optimizing the performance of nuclear glasses over such a time scale aided by a better understanding of their corrosion properties with the near field geological characteristics is challenging because both waste form and site-specific repository conditions (e.g., geochemistry) have to be considered in a synergetic way for the optimization of long term disposal. Known rate-limiting mechanisms for radionuclide release from glass were reviewed during the presentation, based on several processes such as gel layer formation and the accelerated corrosion “Stage III” behavior. In fact, long-standing R&D in this area has already led to a level of mechanistic understanding that has allowed the Yucca Mountain NWPA mandated license review to be processed by the NRC as the definitive destination of Defense HLW. The Subcommittee strongly urges caution that the Department not reference the Yucca Mountain case when pursuing activities seen as “blue sky” research related to corrosion and long-term performance of borosilicate HLW glass in a repository environment. Those objectives are about optimizing (maximizing loading and decreasing volume) the margins of storage conditions using improved scientific understanding and modeling of glass chemistry.

Dr. Paviet also highlighted recent NWTRB activities. Responses from experts convinced NWTRB members participating in a pre-briefing that there was a high level of integration in R&D activities by different DOE offices and programs and by international research and industry organizations. The Subcommittee agrees that the level of cooperation and integration in this area is to be commended. The pre-briefing meeting was followed by the NWTRB public meeting, whose letter of findings was sent officially to the Secretary of Energy and Congress. The Subcommittee seconds the praise for the program by the Board, as keeping up the good work, still with significant scientific uncertainties which remain, particularly related to the detailed causation mechanisms and timing of “Stage III”, i.e., it is of major importance to establish what triggers “Stage III” and to understand if mechanisms exist that could potentially bring about glass corrosion rates higher than current estimates.

The Subcommittee finds that the DOE studies related to glass corrosion made effective use of resources from multiple partners (both within NE-EM-SC in DOE, NEUP projects and international), and had an important goal of helping to arrive at a needed international scientific consensus on long term glass behavior. Continued funding at a reasonable level should be pursued.

Recommendation: Assuming the Yucca Mountain Licensing proceedings begin to move forward under the current Administration, the Subcommittee recommends that all external presentations regarding areas related to scientific and technical subjects addressed in the Yucca Mountain License Application be thoroughly reviewed by knowledgeable legal, technical and licensing staff to assure that the Department’s technical positions on related issues are consistent. The entire Department of Energy is the applicant before the Nuclear Regulatory Commission (NRC) regarding Yucca Mountain, not just the organizational component that provided the submission. More to the point, the NRC licensing process is an adjudicatory process where interveners will be looking for inconsistencies and contradictions in the Department’s scientific and technical positions. As such, the Department needs to move through the licensing process as an integral, focused organization.

VIII. Advanced Reactor Technologies Program – Update

The NE Office of Advanced Reactor Technologies (ART) sponsors research, development and deployment activities with an objective to identify and resolve the technical challenges to enable transition to advanced non-LWR reactor technologies and systems. The NE-4 ART office mission will help support detailed design, regulatory review and deployment by 2030 and beyond.

The ART was restructured to support a campaign structure with National Technology Directors (NTDs in gas-reactor, fast-reactor, molten-salt-reactor) and cross-cutting Technology Area Leads (TALs in energy conversion, advanced materials and special purpose applications). Extensive R&D work in these areas is being coordinated with the DOE-NE Gateway for Accelerated Innovation in Nuclear (GAIN) initiative and is engaging industry that is actively working on advanced reactor designs. The R&D work is also being coordinated with the advanced modeling & simulation initiatives of DOE NE-5 (NEAMS and CASL).

The current ART program also has organized planning activities at three levels:

- **Technology Assessment** – evaluation of the current status of subsystem options and integrated reactor concepts (this has been completed and is documented in the 2017 ATDR Study that was reviewed by NEAC in 2016).

- **Technology Roadmap** – this activity goes beyond assessment, with identification of high priority R&D topics along with timelines and schedules for development of the subsystem technologies. In particular, this work seeks to recognize the key technology challenges and long term R&D needs and it is not vendor specific. This roadmap effort is organized around six Gen-IV reactor classes with a document being developed in each case (sodium-cooled fast reactors, lead-cooled fast reactors, high temperature gas-cooled reactors, gas-cooled fast reactors, salt-fueled molten salt reactors, and salt-cooled molten salt reactors).

- **Technology Development Plan** – this activity goes beyond the roadmap efforts but has not yet been started. This would involve a strategic plan on R&D investments to mature a given concept (i.e., to complete the roadmap path). In general, this would be coordinated with a demonstration product – focused on a specific commercial concept.

These ART efforts are funded in FY18 based on the Continuing Resolution as:

	$K (pre-tax)	Notes
Fast Reactors	17,200	
Gas-cooled Reactors	34,200	Includes TRISO qualification effort under CR.
Molten Salt Reactors	9,600	New focus area in FY18
Energy Conversion	5,000	
Special Purpose Applications	1,800	New focus area in FY18
Regulatory Support	4,000	Managed by NE-5
HQ Project Management/GIF	2,200	
SMR Industry Awards	10,000	To support Advanced Reactor Industry FOA*
Total	84,000	

This new ART structure is an improvement over what was traditionally done, although certain budgetary line items are split between NE-4 and NE-5.

Recommendations:
(1) The Subcommittee would encourage even more coordination between the reactor technology development and the fuel cycle technology development efforts, as well as inclusion of a systems analysis effort to focus on the economics and technology readiness aspects of these systems. In addition, DOE needs to continue close coordination with ARPA-E in crosscutting nuclear technology initiatives; e.g., current MEITNER FOA. These are logical steps to help develop the expertise for an eventual technology development plan.

(2) The Subcommittee would recommend that NE take the 2017 ATDR study and use it as a preliminary guide to create a process by which a technology development plan can emerge for a concept in each technology class. This activity would require nuclear industry input as well as input from the business community.

IX. TREAT Start-up Update

The Subcommittee was provided with an overview of the Resumption of Transient Testing at the TREAT reactor due to the importance of the restart ahead of schedule and under budget, and due to the importance of TREAT transient testing to the Accident Tolerant Fuel (ATF) efforts underway and probable use of TREAT for several of the Advanced Reactor Technologies (ART).

The Subcommittee congratulates the Resumption team for achieving the initial criticality of the refurbished reactor one year ahead of schedule and approximately $20M under budget. TREAT was placed in cold-shutdown in 1994 due to the suspension of the Integral Fast Reactor program and the maturity of the safety case for existing LWR fuels. The success of the resumption program is also a testament to the original design, maintenance during the 1959-1994 operations, and maintenance during cold-shutdown.

TREAT capability has been resumed for several key reasons:

- Accident Tolerant Fuels (ATF) will require transient testing to establish their safety basis – and to quantify the advantage they represent in safety relative to current fuel designs.
- A number of advanced reactor technologies under development may require transient testing of fuel and components to establish failure modes, failure thresholds, and radionuclide source terms.
- Enhanced utilization of the existing LWR reactor fleet may be enabled via improved transient effect quantification, particularly to support advanced analytical tools.

Now that TREAT is critical and progressing through startup physics testing that will culminate with operation at rated power and for "natural burst" (temperature-limited) and controlled transients, the emphasis of the Resumption program is upon test vehicle development, fabrication, and calibration tests. A series of increasingly complex test vehicle designs is planned:

- the MARCH multi-purpose modular static coolant device (first dry test in mid-2018);
- the Multi-SERTTA device for PWR-condition (i.e., high pressure) static water, fresh fuel (calibration mid-2019, first fueled test 2020);
- the Super-SERTTA device for PWR-condition static water, irradiated fuel (deployed 2021-2022); and potentially:
    - the TWERL device for PWR-condition convective water, fresh or irradiated rods and/or bundles;
    - the RETINA video-capable vehicle;
    - the Mk-IV Sodium Loop (convective liquid metal, fresh or irradiated pins and/or bundles).

The Subcommittee strongly recommends that the set of test vehicles developed be "standardized test vehicles" able to perform testing on a significant variety of fuel samples within the environmental range for which that "standardized test vehicle" is designed. The instrumentation supported by each "standardized test vehicle" should be developed with the targeted user-community (vendors and regulators) to assure that the detailed test conditions and responses to the transients are measured appropriately for the data required by the user community. In addition to the vehicle design, fabrication, and qualification, the related infrastructure of the HFEF hot cell must be re-established and/or adapted to support testing of irradiated test specimens.

Work to convert the TREAT reactor to LEU driver fuel is underway, and is being coordinated with future experimental needs. The fact that the modernized reactor safety basis of TREAT is now complete will facilitate conversion design and safety analyses.

The Subcommittee looks forward to continued updates from the TREAT team as the ATF tests proceed and the requirements for transient tests for advanced reactors mature. TREAT test requirements and test availability will be important components of schedule and budget development for ATF licensing and ART Technology Development Plans.

A concept for the potential use of TREAT transients as a “science tool” to provide separation of effects for multi-scale material science experimentation modeling was described. The Subcommittee does see potential benefit in the ability to treat the time scale distinct from length scale, and encourages an additional scoping study of the potential use of TREAT as a “science tool.”

In addition to emphasizing the value of separate effects testing, the Subcommittee wishes to indicate that running all tests to failure, as was done at times in the past, is not the most informative testing strategy. Tests which are bounding, but not run to failure, are often more informative when developing the Design Basis Accident position to be included in Chapter 15 of the Final Safety Analysis Report (FSAR).