

Report to NEAC
Fuel Cycle and Infrastructure Subcommittee
Meeting of January 24-25, 2019

Washington, DC

March 14, 2019

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I. Introduction

The agenda for the January 24-25, 2019 Fuel Cycle and Infrastructure Subcommittee meeting is shown below. The meeting provided members an overview of several research efforts funded by the DOE Office of Nuclear Energy's Fuel Cycle and Supply Chain Office (NE-4), and related research that is coordinated with NE-4. All members of the Subcommittee, except Joy Rempe (on foreign travel), were present. One Subcommittee member, Ray Juzaitis, resigned prior to the meeting to pursue other activities. Pete Lyons, Co-Chair of the Existing Fleet Subcommittee, joined the group for both days.

Agenda

Chair: Dr. Alfred P. Sattelberger; Co-Chair: Dr. Ralph Disibio

Location: Argonne National Laboratory, L'Enfant Conference Room B15 – 6th Floor

Thursday, January 24:

8:30	Arrive Argonne Office and Sign-In
8:45–9:00	Executive Committee – Closed Session
9:00–9:30	Opening Remarks NE-1
9:30-10:15	Introduction NE-4
10:15	Break
10:30-11:00	Budget
11:00-11:30	NE Related Congressional Legislation
11:30-12:15	Experimental and Testing Facilities Update
12:15-1:00	Lunch
1:00-1:30	Accident Tolerant Fuel (ATF) Update
1:30-2:15	EPRI Presentation (Safety Benefits Task Force)
2:15-3:15	ATF Vendor Presentation (GE)
3:15	Break
3:30-4:45	Versatile Test Reactor
4:45-5:15	Closed Session – Summary of Day 1
5:15	Adjourn for Dinner

Friday, January 25:

8:30	Arrival and Check-in
8:45-9:45	ATF Vendor Presentation (Framatome)
9:45-10:30	Fast Reactor Metallic Fuels Update
10:30	Break
10:45-11:30	ZIRCEX Briefing
11:30-12:00	Working Lunch
12:00-12:45	NEUP and User Facilities Update
12:45-1:45	ATF Vendor Presentation (Westinghouse)
1:45-2:30	Closed Session – Writing Assignments
2:30	Adjourn

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

I. Opening Remarks NE-1

Ed McGinnis, Principal Deputy Assistant Secretary for Nuclear Energy, opened the meeting by phone. He discussed, *inter alia*, the importance of revitalizing the U.S. nuclear fuel cycle (FC) and specific FC-related efforts, including the Versatile Test Reactor (VTR), the ZIRCEX demo, used EBR-II fuel processing for High Assay Low Enriched Uranium (HALEU), the HALEU enrichment demo, advanced fuels/Accident Tolerant Fuels (ATF), and the Transformational Challenge Reactor (TCR). Ed stressed that this is a critical time for DOE-NE. The NE Office is engaged on multiple fronts, including at the back end of the fuel cycle and at the front end, with the development of a new multi-billion dollar test reactor, as well as fuel supply issues and advanced additive manufacturing. NE is also working to open up the advanced reactor pipeline, including micro-reactors, small modular reactors (SMRs), and large non-light water reactors. They are working multiple issues simultaneously.

One of the perceived highlights of the current NE strategy is the Versatile Test Reactor (VTR). The U.S. has been without a fast test reactor since the 1990s. China and Russia are much further along on this front. Promoting advanced reactors and advanced fuels is difficult without a domestic fast-spectrum test facility. NE is just entering into the DOE Critical Decision (CD) process (DOE Order 413.3B) for the VTR. A major challenge is to restore confidence that DOE can indeed build a multibillion-dollar test capability for our country.

With regard to the existing fleet, NE is investing in Accident Tolerant Fuels. The goal is to have industry get these products into the market place by 2023 or 2024 in time for utilities to benefit from the technological advances, and before they have locked in long-term contracts for traditional fuel.

In the disruptive category, NE is investing in additive manufacturing. The Transformational Challenge Reactor (TCR) is not a 'new' reactor, but rather a demonstration of a very innovative approach to additive manufacturing through 3-D printing. Oak Ridge National Laboratory (ORNL), Idaho National Laboratory (INL), and others are pursuing this technology as it applies to nuclear reactor components.

Ed expressed optimism that new reactors are on the horizon. The first micro-reactor will probably submit its combined license (COL) application to the NRC later this year. Ed foresees that it will be the beginning of many such applications, but they will have trouble getting off the ground if they do not have a supply of HALEU fuel. An aggressive timeline is evolving for HALEU needs, and the fuel cycle infrastructure will be racing to catch up by the 2022 or 2023 time frame. Processing EBR-II fuel may provide an initial modest supply and buy us a little time.

DoD is pushing two pathways for micro-reactors. One is stationary infrastructure at domestic facilities/bases through power purchase agreements, in addition to transportable reactors for deployed bases. They are talking to micro-reactor companies now and they are looking for a demonstration in Idaho as a key first step. As a result, we may have a sudden high-volume requirement heading our way for HALEU that must be delivered through our fuel cycle infrastructure. NE is working closely with DoD to ensure feasibility.

The last issue Ed mentioned was the current fleet of nuclear power reactors. The current fleet market is not under NE's sphere of influence, but there are many state and other issues where NE can provide assistance.

In the Q&A period following Ed's remarks, it became clear that one of the community's needs is an elevator speech that can explain what NE is trying to accomplish with its strategic objectives in a compelling, non-technical way. There was no assignment offered for this challenge. We were pleased to hear that the monthly Atomic Wings Lunch & Learn sessions on the Hill that Suzie Jaworowski and the front office team organized continue to be well-attended. On January 22, Ms. Jaworowski released an e-book that describes what NE is doing (<https://www.energy.gov/ne/downloads/ultimate-fast-facts-guide-nuclear-energy>).

II. Introduction NE-4

John Herczeg, the Deputy Assistant Secretary for the Nuclear Fuel Cycle and Supply Chain, discussed the changing landscape at HQ, including the reorganization of NE, the HALEU cascade demonstration project, and the ZIRCEX program (direct chlorination of used nuclear fuel to remove Zircaloy cladding). There are now just two offices under NE-4. One is the Office of Advanced Fuels Technologies (NE-42) led by Bill McCaughey, that includes all the advanced fuels work and now the enrichment demo program. The other is the Office of Materials and Chemical Technologies (NE-43) with Dan Vega as the acting director. NE-4 is the fuel supplier to the Office of Reactor Fleet and Advanced Reactor Deployment (NE-5). The expansion of NE-42 and NE-43 is significant. The ZIRCEX project resides in NE-43. The former NE-41, the Office of Advanced Reactor Technologies, moved in the Fall to NE-5. These changes took place and were official in early January. We believe that more communication with the Subcommittee would be helpful as these changes evolve.

John spent some time describing the evolution of the HALEU Cascade Demonstration Program which, when up and running, will consist of 16 machines (AC 100Ms) and attendant support equipment operating in a cascade configuration/recycle mode. From a previous campaign, there were parts for 8 centrifuge units and most of the parts for 8 more (16 is a magic multiplier number called a cascade). NE-4 put the proposal package together and worked with the firm Centrus. The goal is to produce HALEU in gram quantities by 2020, and multi-kilograms in 2021. John requested and was given a 3-year \$115M budget to prove the technology at the TRL-9 level. Everything had to be cleared by the Office of General Counsel in DOE. Optimistically, the contract will be issued next month. John and his team are confident that all the technical problems are resolved, but won't know for sure until the units run for a year.

John then described the estimated annual requirements for HALEU out to 2030. He presented a table with 8 columns representing individual advanced reactor vendors and rows indicating their projected needs (in MTU) from 2018-2030. The total number of metric tons needed starts to increase significantly in 2023. Micro-reactor needs were not included in the table. The advanced reactor vendors collectively estimate they will need roughly 600 tons by 2030. Even if the true number is only 100 tons, that's a lot of material – through enrichment or ZIRCEX. NE-4 is not wedded to the chart, but apparently many industry folk are. John believes that a prudent strategy would be to make smaller amounts of material available and to initiate a demonstration. The marketplace can then determine if it wants to make HALEU in production mode. John then described the HALEU funding profile. The first installment of funding is \$35M to bring the manufacturing capability back up in a classified facility and install the cascade in 2020. Centrus won't produce more than gram quantities because of the operating license requirements. John questioned whether NE is doing a program that will lead to an early commercial market ramp-up as industry predicts, but noted that this demonstration provides enrichment options based on U.S. technology for the future. Based on what the Subcommittee heard, it sounds reasonable. A sole source Notice of Intent (NOI) went out on January 7 – it encouraged anyone that believes they

can do this work to please step forward and submit information on their technology. After 15 days, there were no submissions.

John ended his presentation by reinforcing the Subcommittee’s role to provide candid, open and expert advice, and noted that our Subcommittee reports are highly valued in the NE decision-making process as well as with Congress and Executive Offices such as the National Security Council (NSC) and the Office of Science and Technology Policy (OSTP).

III. Budget Update

Daphne Miss-Lugenbeel reviewed the NE-4 FY19 budget and the breakout funding by Campaign (see below). Surprisingly, NE-4 received their entire appropriation by Oct 1st; this was somewhat unprecedented. Daphne backed up to FY 2018 and reminded us that she is working on three budgets in any one given year: executing the Enacted FY18 budget, justifying the FY19 budget with OMB, and formulating the FY20 budget. The FY20 budget has two new areas: Enrichment and ZIRCEX. These two new lines show up in the FY20 budget request but are not spelled out in the FY19 budget.



U.S. DEPARTMENT OF
ENERGY

Nuclear Energy

Nuclear Fuel Cycle and Supply Chain FY 2019 ENACTED Funding by Campaign

Campaign	Funding (\$000s)		Notes
	FY 2018 Enacted	FY 2019 Enacted	
Advanced Fuels	101,800	101,125	Advanced LWR fuels, metallic transmutation fuels, crosscutting capability development
Civil Nuclear Enrichment	0	30,200	FY 2019 Enrichment amount is \$35M, of which \$4.8M comes from UNFD Prior Year funds.
Material Recovery & Waste Form Dev't	15,620	25,016	Aqueous, electrochemical, waste forms, off-gas technologies. \$20M of the \$25M is earmarked for Zircex.
Joint Fuel Cycle Studies	4,360	7,000	US-ROK collaboration on electrochemical reprocessing. 50/50 Cost Share with ROK.
Systems Analysis and Integration (aka FCO)	7,500	4,209	Evaluation and screening, analyses, fuel cycle catalog
MPACT	7,200	4,425	Material protection, accounting, and control technologies
Integ Waste Mgmt System	22,500	22,500	The Department is directed to continue research and development activities on long-term storage, transportation, and disposal of spent nuclear fuel and wastes.
Used Nuclear Fuel Disposal R&D	48,650	50,492	
NEUP	33,610	10,580	Competitive awards to universities, supporting all of the technical campaigns
Headquarters-Directed Activities	6,536	6,578	Special projects, support services, management reserve
SBIR/STTR	10,410	11,115	Small Business Innovation Research/Small Business Technology Transfer
Program Assess. & Coordination	1,870	1,475	Project management, program support
Use of Prior Year Funds		-10,800	FY 2019 Enrichment amount is \$35M: \$30.2M from FY 2019 funds; \$4.8M from UNFD Prior Year funds; and \$6M from NfCSC Prior Year funds.
Total	260,056	263,915	

N.B. the \$30.2M entry on the ‘Use of Prior Year Funds’ line should read \$24.2M.

A lively discussion ensued about the budget process. John Herczeg noted, along with Daphne, that the discrepancy between the amounts they request and the amounts they receive causes significant execution problems with multiyear projects. The chart displays what the office actually executes. The first 6 rows are campaigns within Fuel Cycle and Supply Chain. The 20% NEUP and other taxes are taken

out; what you see is the net. When you see the bottom line, it is all within the same funding control. Then, NE-4 had to come up with \$35M for enrichment. The net result was that NEUP contributions went from 20% to 10% in FY19. There is a line in the new budget that will cover enrichment. Many of the Subcommittee members present expressed concern about the hit to the NEUP budget. John Herczeg is also quite concerned. Daphne commented: we are mandated at \$35M and we cut the campaigns as much as we could and then had to look at NEUP. The dilemma was discussed with upper management and this was the solution. Daphne further noted that VTR (which resides under Advanced Reactor Technologies) was funded at \$65M in FY19.

IV. NE Related Congressional Legislation

A comprehensive summary of recently enacted and currently pending NE-related legislation was provided to the Subcommittee, along with a discussion of new statutory direction that will need to be undertaken by NE. The presenter (Brad Williams) stated that since 2015, 20 bills on nuclear related issues had been introduced with four having been reported out of Committee for floor action. Five bills were actually passed by the House or the Senate, with four being enacted into law. Of note was the fact that six of the bills under consideration addressed nuclear waste related issues. The presentation also indicated the current year NE budget was the largest ever appropriated to the program - \$1.3 billion. According to the presenter, Congressional support for Nuclear Energy is strong and bi-partisan with legislative efforts to assist the industry focusing on current fleet issues, advanced reactor concepts, regulatory streamlining, and technical innovation.

Most of the discussion was focused on the recently enacted Nuclear Energy Innovation Capabilities Act (NEICA), which was signed into law by the President on September 28, 2018. NEICA directs DOE to determine the mission need for a versatile reactor-based fast neutron source by December 31, 2017, and approve the operation of such reactor by December 31, 2025. (As with most legislation that takes years to develop and enact, the statutory planning dates in NEICA reflect the timeframe when the legislation was introduced, and, as such, were never updated in the legislative process to reflect the actual date of enactment.) Besides the versatile test reactor direction, NEICA also authorizes DOE to partner with industry to create a cost-sharing program to help defray the cost of advanced reactor licensing, directs DOE to expand high-performance computer capability focusing on advanced reactor modeling simulation capability, and establishes the National Reactor Innovation Center.

Although not directly related to NE activities, the recently enacted Nuclear Energy Innovation Modernization Act (NEIMA) was also discussed. NEIMA was enacted into law with the President's signature on January 14, 2019, and focuses on NRC-related activities. Among other directives, NEIMA revises the NRC fee structure for existing reactors, directs the NRC to establish a licensing framework necessary to enable the licensing of advanced nuclear reactors no later than December 31, 2027, and directs the NRC to establish a pilot project for uranium producers to allow predictable fees for routine licensing matters.

Other recently enacted legislation of note included the Production Tax Credit Extension (codified in the Bi-partisan Budget Act of 2018) providing the extension of tax credits for Advanced Nuclear Reactors and the John S. McCain National Defense Authorization Act of 2019 which directs DOE to develop a report on a pilot program for micro-reactors for critical national security infrastructure needs at DOE and DOD facilities by December 31, 2027.

The Subcommittee notes the lack of any legislative progress to address the waste disposition issue in the past Congress. The current Administration has requested funding to restart Yucca Mountain, but

Congress has yet to authorize restart. The Subcommittee continues to believe the lack of a high-level waste disposition pathway will remain an impediment to future nuclear industry facility deployment and public acceptance.

V. Experimental and Testing Facilities Update

Since the May 2018 Subcommittee review, the feared permanent closure of the Halden Boiling Water Reactor (HBWR) has occurred in Norway. Most evolutionary LWR fuel designs developed and under development by vendors in the U.S. and abroad have been irradiated in the HBWR, either as part of the OECD Halden Project or in proprietary testing campaigns negotiated between vendors and the Norwegian Institute for Energy Technology (IFE) that operates the HBWR. The U.S. NRC, EPRI, and other regulators have performed test campaigns in the Halden Project to obtain in-pile data that are critical for characterizing lifetime-limiting fuel phenomena, such as: fuel thermal conductivity degradation (TCD), pellet cladding mechanical interaction (PCMI), irradiation-assisted stress corrosion cracking (IASCC), axial offset anomaly (AOA), and loss of coolant accident (LOCA) fuel dispersion. The reactivity ramp testing capability at the HBWR was particularly strong, with few such capabilities available in the world.

The IFE staff at the HBWR was the unparalleled world leader in reconstitution of irradiated fuel into test rods or rodlets for additional testing, and in the design and implementation of instrumentation of irradiation tests to collect in-situ performance data at both steady state and ramped-power conditions. Such testing was cost effective and highly reliable because the HBWR used a set of standardized test rigs that had been designed for flexible instrumentation. Another unique aspect of the HBWR testing programs was the well-established transportation capabilities to several of Europe's hot cells, particularly Studsvik in Sweden. The Studsvik hot cells are allowed to accept LWR test specimens up to full length and high burnup. Furthermore, Sweden is able to dispose of the test articles after hot cell examinations are completed.

The loss of the HBWR poses a significant challenge to the global nuclear industry, including the ATF program under NE-4 purview. The ATF program and specific vendors had been planning HBWR irradiations to address the volume of data required for licensing, and for ramp testing in particular. INL staff (Colby Jensen) representing the Advanced Fuels Campaign briefed the Subcommittee on a gap analysis regarding ATF Program plans for fuel development and qualification after Halden closure, and associated recommendations. The presentation summarized reports prepared in the second half of 2018: INL/EXT-18-46101 R0 that described preliminary output of a July 2018 workshop of DOE, industry, and test reactor representatives; and INL/EXT-18-46101 R1 that presented the final recommendations, vetted by the ATF fuel vendor needs survey and the ATF industry advisory committee. Fortunately, in conjunction with the successful restart of the TREAT transient reactor in 2018, the Advanced Fuels Campaign was already working to:

- Accelerate development of LOCA testing capability at TREAT
- Improve capabilities and capacity for irradiated fuel rod refabrication and reinstrumentation for additional in-pile testing
- Improve in-pile instrumentation

However, it is now clear that additional pressurized water loop irradiation capacity, for irradiating fuel at PWR and BWR conditions, must be developed for test reactors, particularly to allow ramp testing of fuels. The INL team presented pre-conceptual designs of test loops that could be deployed at ATR, including ramp capability. INL has begun formal collaboration with IFE to design a power ramp testing rig for the ATR.

The Subcommittee applauds the effort at INL to address the Halden Gaps, especially the inclusion of expertise from Halden, the other national laboratories, and partners in industry and academia. Such teaming will be vital to addressing the Halden Gaps in a timely, effective, and reliable manner.

Recommendations:

- (1) The Subcommittee strongly recommends that a new pressurized water loop be developed for the ATR, including ramp capability and a standardized test rig to contain instrumented fuel rodlets.
- (2) The Subcommittee also strongly recommends that the loop and standardized test rig be developed as a collaboration of IFE experts from Halden; industry user representatives; experienced in-pile experiment researchers from HFIR (ORNL), MITR (MIT), and other ATR irradiation programs; and subject matter experts from other national laboratories and universities. Said collaboration should include the multiple institutions in the formal design review processes. Input from the CEA in France and SCK-CEN in Belgium during the process would help assure coherence with international efforts to address the broader Halden Gap previously discussed.
- (3) The Subcommittee recommends that the ATF program establish limited redundant capabilities for irradiated fuel refabrication and reinstrumentation into test rodlets at PNNL or ORNL in order to mitigate the risk of irradiated fuel transportation impediments (i.e., the current moratorium regarding irradiated fuel shipment into Idaho) or other sole-source delays such as hot cell capacity and or operational disruption issues.
- (4) The Subcommittee is concerned that a new test loop and standardized test rig to address the Halden Gap will be particularly difficult in terms of both budgetary and expert resources during this period of expanding activities, including but not limited to TREAT transient testing expansion, ATR Core Internals Changeout [CIC], VTR design and deployment, ATF, HALEU, etc. The need to address the Halden Gap is imperative if ATF is to succeed, and to address the broader needs of DOE's LWR Sustainability program, LWR fuel vendors, and the NRC.
- (5) The Subcommittee notes that disposition of test samples harvested from commercial irradiated fuel after completion of Post Irradiation Examination (PIE) may continue to pose a challenge for U.S. hot cells, such as the challenges currently being experienced at INL.

VI. ATF Program Update and Vendor Presentations

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 Light Water Reactors (LWRs). Vendors are pursuing a strategy which relies on the ability of ATFs to extend the time before initiation of the exothermic oxidation reaction associated with hydrogen generation from the Zircaloy-based cladding in current LWR fuel.

During Subcommittee reviews in December 2017 and May 2018, the ATF Program communicated a number of challenges to the schedule, to the definition of metrics for fuel performance safety advantages and associated licensing requirements, and to the metrics of a commercialization business case. The Subcommittee requested substantial review of the experimental program plan, NRC engagement, and the commercialization business case.

The Subcommittee appreciates the diligent response by the ATF Program Manager to the comments and observations made by the Subcommittee in previous NEAC reports. The Program Manager addressed each comment and presented the ATF Program response to each. This approach in responding to Subcommittee comments is both recognized and appreciated.

The Subcommittee also appreciates the coordination of many presentations at the current review by the program, EPRI, NEI, and industry participants: GE, Framatome, and Westinghouse.

As discussed in greater detail in Section VII of this Subcommittee report, EPRI and the NEI presented summary results of independent analyses of the ATF fuel product proposals with regard to both accident benefit and economics. Their conclusions are briefly summarized:

- While the safety benefit due to enhanced coping time before exothermic cladding oxidation reaction is insufficient to avoid core damage without re-establishment of minimal core cooling after a Beyond Design Basis Accident (BDBA), the improved coping time could work well in concert with low pressure coolant injection such as Reactor Core Isolation Cooling (RCIC)/Auxiliary Feedwater (AFW)/Diverse and Flexible Coping (FLEX) strategies.
- The ATF designs appear to offer significant benefit for a number of Design Basis Accident (DBA) scenarios, particularly for fuel at higher burnups. Such benefits would translate to operating margins that would offer cost benefits both in terms of operational flexibility and fuel cycle optimization.

As noted in our prior reports and in Section VII below, data are required to support many assumptions in these evaluations. In addition, we continue to emphasize that the benefits of ATF must consider the entire reactor response, considering combustible gas produced by other components, besides cladding, that contain stainless steel and zirconium-based materials such as grid spacers, channel boxes, and support structure. In addition, the response of the reactor must be considered when the fuel remains in a coolable geometry, but control materials may have degraded and relocated.

The ATF Program has responded to the EPRI and NEI feedback, together with prior Subcommittee recommendations, to refine the division of the program into two phases of ATF licensing:

- First, in Phase 1, high Technology Readiness Level (TRL) fuel enhancements will be licensed that are “at least as safe as current fuel” via Lead Test Rod, Lead Test Assembly, and targeted ATR testing for separate effects examination.
- Second, in Phase 2, expanded testing will be used to develop the licensing bases for the safety benefits that could lead to higher burnup utilization and improved operational flexibility. The lower-TRL fuel enhancements will be advanced for longer term improvements. The testing to complete Phase 2 would include TREAT experiments, and instrumented ramp testing in a facility that can replace the Halden capability (see Section V of this report).

GE, Framatome, and Westinghouse each presented proprietary, business-sensitive updates of their plans to execute the two-phase approach to ATF success under the new Cooperative Agreements with the DOE that were established in 2018 (effective October 2018 – January 2021).

GE is pursuing ARMOR Coated Zircaloy Cladding as their highest TRL concept, with IronClad FeCrAl as a longer-term concept. ARMOR may have fewer safety benefits, but also less of a cost increase with respect to current fuels.

Framatome is pursuing PROTECT fuel with Cr-Coated M5[®] Cladding and Chromia-Doped UO₂ fuel pellets as their higher TRL product, with longer term plans to use SiC cladding rather than Cr-Coated Zircaloy-based M5[®] cladding. Framatome described three near-term lead test assembly (LTA) irradiations that will include PROTECT ATF lead test rods (LTRs), and a subsequent irradiation of 2 complete ATF LTAs (i.e., all rods of the LTAs to be PROTECT ATF fuel). In addition to those demonstration tests, Framatome has scheduled irradiation of fuel samples in ATR and TREAT, a Swiss power reactor, and Cr-coated M5[®] tube specimens in HFIR. Framatome is engaged in hot cell work at INL, ORNL, and PNNL.

Westinghouse is pursuing EnCore™ fuel as their higher TRL priority ATF concept, with the ADOPT™ Chromia-Al-doped UO₂ pellets clad by Cr-coated Zirlo™. The ADOPT™ pellets already are used in Europe, but not the Westinghouse coated cladding. Their longer-term plan is to deploy Uranium Disilicide (U₃Si₂) fuel pellets clad by General Atomics' SiGA™ SiC composite, but each of those technologies is less mature than EnCore™. Westinghouse described their plan to use advanced modeling and simulation to improve prioritization and effectiveness of fuel testing and thus accelerate the licensing process.

Each vendor and the DOE NE ATF Program highlighted increased interaction with the NRC. A Phenomena Identification and Ranking Technique (PIRT) process began for coated cladding in October 2018, with involvement of EPRI, the NRC, PNNL, and other experts. Draft interim guidance from the NRC is expected in the summer of 2019, to be followed by public meetings and final interim staff guidance by the end of calendar year 2019. The vendors described specific interactions with the NRC for the Lead Test Rods (LTRs), Lead Test Assemblies (LTAs), and development of the requirements to obtain a full-batch reload license.

Table 1 summarizes the current schedule for ATF lead test assembly (LTA) irradiations in commercial plants. As indicated in Table 1, transportation issues led to unfueled samples of cladding material being inserted into Hatch, rather than pins with fuel contained with the new ATF cladding materials.

Table 1: Near-term Accident Tolerant Fuel LTA Irradiations

Vendor	Description	LTR/LTA Irradiation	
		Date	Plant
GE	Full-length test rods, segmented rod design: <ul style="list-style-type: none"> Unfueled IronClad Alloy Cladding [Iron-Chromium-Aluminum, FeCrAl] UO₂ Fueled ARMOR Coated Cladding* 	Spring 2018	Hatch Unit 1 BWR
	Full-length test rods, segmented rod design: <ul style="list-style-type: none"> UO₂ Fueled and Unfueled IronClad Alloy Cladding [Iron-Chromium-Aluminum, FeCrAl] UO₂ Fueled and Unfueled ARMOR Coated Cladding* 	Fall 2019	Clinton Unit 1 BWR
Framatome	4 LTAs with 4 full-length ATF rods <ul style="list-style-type: none"> PROTect fuel [Chromium-Coated M5® Cladding (eATF) on Chromia-doped UO₂ Fuel] 	Spring 2019	Vogtle Unit 2 PWR
	2 host assemblies with 10 Cr-Coated M5® LTRs (filled by UO ₂ or Chromia-doped UO ₂)	Summer 2019	Proprietary
	8 LTAs with 2 rods of Cr-Coated M5® and UO ₂ 8 LTAs with 2 unfueled rods of Cr-Coated M5®	Fall 2019	Proprietary
	2 LTAs with all rods PROTect [Chromium-Coated M5® Cladding (eATF) on Chromia-doped UO ₂ Fuel]	Spring 2021	Proprietary

	Rodlets of SiC cladding on Chromia-doped UO ₂ Fuel	2022	TBD
Westinghouse	LTRs of EnCore™ [Chromium-coated Zirlo™ Cladding on ADOPT™ (Chromia-Al-doped UO ₂) Fuel]	Spring 2019	Byron Unit 2 PWR
	Rodlets of SiC Cladding on Uranium Disilicide (U ₃ Si ₂) Fuel	2022	TBD

*The ARMOR coated cladding was first developed outside of the DOE ATF program, but ATF is instrumental to licensing of the ARMOR fuel.

Recommendations:

- (1) The Subcommittee recommends that the engagement with the NRC continue to be strengthened via the PIRT processes or similar approaches for doped-UO₂ and U₃Si₂ fuel pellet licensing. Such early interaction will be especially important to realize any ambition of modeling and simulation to refine fuel test programs for accelerated licensing.
- (2) The Subcommittee strongly recommends that DOE NE continue to refine the specific strategy for DOE reactor irradiations and PIE to include specific input from the regulator as to what data are required for rendering regulatory decisions. The revised strategy should describe upgrades required at the facilities or their instrumented-experimental capabilities. It is highly unlikely that ATF can be commercialized without implementing a revised strategy that combines ramp testing in a new ATR pressurized water loop with standardized test rig in addition to the TREAT testing already planned.
- (3) The Subcommittee recommends that a roadmap be prepared for the business case of commercialization with existing burnup limits, then extension to higher burnups for improved economy. This roadmap should explicitly identify what data will be required by the regulator to obtain the anticipated economic benefits. Plant owners/operators will clearly need to have high confidence in the extended burnup limits to adopt the ATF products during the period of economic challenge.

VII. EPRI Presentation

EPRI provided a historical perspective and a current update on efforts to assess the potential benefits of Accident Tolerant Fuel (ATF) within the existing and newly deploying nuclear fleet. The remainder of a series of EPRI and NEI reports (initial studies were issued in 2017 and 2018) will be publicly available in the coming months that will document efforts to assess the technical gaps/efficacy and the economic and safety benefits of ATF. Substantial industry stakeholder involvement and input greatly assisted the EPRI assessment efforts. The presenter also forthrightly acknowledged the “heavy lift” of deploying the near term use of ATF given the typically long lead times needed to develop new fuels and the projected end dates of several plants that have indicated their impending retirement. As indicated during the presentation, the industry is committed to supporting ATF batch reloads by 2023 with full core reloads by 2026.

The initial EPRI ATF Valuation 1.0 Assessment issued in October 2017 addressed potential 10 CFR Part 50.59 risk informed safety benefits and evaluated potential ATF benefits for Beyond Design Basis Accidents (BDBA) and limited Design Basis Accidents (DBA) and Anticipated Operational Occurrences (AOO). Key findings in the 1.0 Assessment included the variability of benefits due to different ATF concepts, that ATF safety benefits need to consider total system performance, and that significant delay (6-12 hours) in core damage is possible, although much of this time is due to ATF being combined with

other accident mitigation strategies such as the newly installed FLEX equipment and increased credit associated with RCIC and ATW operation. Although additional data are needed to support the conclusions from their evaluations, analyses indicate that some ATF concepts may have reduced the amount of core damage at TMI-2. There are also potentially greater economic benefits in operational margin improvement for Large Break Loss of Cooling Accidents (LBLOCA), assuming that actual fuel changes are implemented and not just cladding changes, and that use of ATF could enable other system effects which may, in turn, offer greater safety and economic benefits. However, as indicated in several of our prior reports, the Subcommittee still questions how ATF proponents will achieve these benefits without also considering the response of the entire core. Phenomena, such as combustible gas production by other stainless steel and Zircaloy components and the potential relocation of control rods at temperatures below those at which ATFs are predicted to degrade, must be addressed to support the safety and economic case for ATF deployment.

EPRI ATF Valuation 2.0 was published in December 2018 and provided a potential “buffet” list of enabled ATF benefits when the system effects are more rigorously and comprehensively evaluated. Site visits emphasized that reducing margins may lead to potential savings that are generic and site specific. The potential benefit categories identified in Version 2.0 include Fuel Cycle Optimization, Improved Operational Flexibilities, Enhanced Fuel Performance, Improved Coping Times and Enhanced Fuel Reliability. Version 2.0 confirmed and expanded many of the findings in Version 1.0. Of major focus were the enabling capabilities of ATF usage especially in Fuel Cycle Optimization, including improved fuel cycle efficiencies such as improved cladding performance, potential increased burnups, increased enrichments, potential longer fuel cycle lengths leading to reduced waste generation and operational costs. The economic benefits of the Version 2.0 analyses will be articulated in the upcoming EPRI and NEI economic analyses to be issued in early 2019.

The Subcommittee is strongly supportive of the EPRI and NEI efforts to assess the efficacy and benefits of ATF within the nuclear industry and appreciates the “heavy lift” that near-term deployment of ATF technology faces. Although assumptions invoked in EPRI’s Valuation 2.0 Assessment must be supported with data, the evaluations are a good step toward identifying potential aspects of the ‘business case’ for ATF deployment. In this regard the Subcommittee looks forward to the upcoming EPRI economic reports and is pleased that the reports will be publicly available. Regarding the schedule for implementation, although not specifically addressed in the EPRI and NEI analyses, the Subcommittee believes NRC acceptance of ATF will be on the critical path for batch load and eventual core load schedule goals. In addition, the road to the realization of many of the identified potential benefits of ATF is complicated, as they rely on near term ATF utilization and the achievement of higher burnup and longer operating cycles. The Subcommittee also notes that the EPRI valuations only show the positive benefits of ATF with no identified dis-benefits other than economic costs. Accordingly, the Subcommittee believes a more even-handed presentation of ATF impacts, identifying the required data and additional evaluations required to support ATF deployment, would instill greater overall confidence in the study results both within the nuclear industry and with the general public.

VIII. Versatile Test Reactor

The Project Manager (PM) for the Versatile Test Reactor (VTR) provided an overview presentation of the entire project to the Subcommittee. The PM had first updated the Subcommittee in May, 2018 and this presentation was an update to the information we received at that time. The overview covered the entire project, including the activities currently performed by the national laboratory team and included the experiment development program. A short summary is included below, along with current conclusions and recommendations.

Summary

The VTR Project seeks to provide experimental capabilities that will benefit advanced reactor design concepts particularly in fuels and materials testing. The Project has developed a testing strategy to raise the Technology Readiness Levels (TRLs) associated with the major reactor technologies; specifically for the Sodium-Cooled Fast Reactor (SFR), the Lead-Cooled Fast Reactor (LFR), the Gas-Cooled Fast Reactor (GFR), the Modular High-Temperature Gas Reactor (MHTGR), and the Molten Salt Reactor (MSR). These are reasonable and notable activities.

There needs to be a planning and parallel activity to engage and develop the potential community that would use the VTR for future experiments. This activity would have two purposes. First, such an activity would allow the Project and the experimenter community to engage in a discussion to better identify test and instrumentation needs for the VTR. Second, this activity would expand the support base for the VTR over the interim as it is being designed. The objective of this engagement plan would be to identify the customers and define the experiments needed by these customers, and this could feed into the business case that DOE would be expected to develop.

Conclusions and Recommendations:

The PM gave an energetic and comprehensive presentation. The discussion with the PM was helpful and the Subcommittee has a set of conclusions and recommendations:

(1) The approach taken by the VTR PM is encouraging and the Subcommittee agrees with the DOE plan to identify and hire an on-site federal project manager so that DOE-NE can more effectively and efficiently work with the PM as the VTR Project grows in scope and scale. We also commend the VTR Project on the selection of a deputy PM to assist with the technical issues that may arise during the VTR design phase.

(2) The Subcommittee had previously recommended that the project develop a clear regulatory approach for the VTR. We were pleased to hear that this has been accomplished. The plan presented will have the VTR licensed by DOE orders with final approval by the DOE-ID office. The DOE-ID office will assemble the needed technical support organization and recruit the needed experts to carry out the review. This will be a challenge since the number of experienced personnel sufficiently familiar with the sodium fast reactor technology is limited. Engaging international experts may be one way to expand the expertise base, e.g., French and Japanese experts. A draft DOE-NRC MOU on Versatile Test Reactor Engagement, currently under review at the NRC, allows the NRC to inform their own licensing regulatory development by observing a DOE process, and provides an opportunity for outside feedback to the DOE Approval Authority.

(3) The Project has the challenge of adapting the PRISM design, which is a design for a power reactor, to that of the VTR, which is a test reactor. The VTR Project recognizes this and is identifying modifications needed to the reactor core, refueling equipment, and heat rejection systems, as well as the need to be able to handle longer test vehicles.

(4) It is evident to the Subcommittee that the Project is in its early planning stages. Current cost estimates for the VTR range between \$3.4 to 4.7B, which will make this project the largest capital project in the history of the DOE-NE. We acknowledge that NE is aware that the VTR Project is to be covered by DOE O413.3B, which provides the requirements envelope under which the cost/scope/schedule needs to be developed (since the VTR has expanded from an “initiative” to a “project”). Therefore, as the project moves forward and the design matures, the Subcommittee strongly recommends that:

- The Project needs to develop a best-cost estimate and an associated design, construction, testing and operation schedule.

- To provide a sound basis for the latter, the Project needs to develop an integrated, resource-loaded schedule including core design, reactor plant design, test vehicle design, and including procurement, installation, and construction.
- The Project should also identify the critical path within this schedule along with potential areas that could delay the project. The project will need to develop contingency plans in the event such delays should occur. This would also help the project to identify the set of key issues that would need to be addressed to be able to manage potential delays in advance.
- The Project has been successful in developing a Laboratory-University-Industry team to develop future experiments for the VTR. This is a good first step for the project. The Subcommittee recommends that the project develop an engagement plan to identify additional industrial customers and develop an understanding of their experimental needs.
- A project of this scope and magnitude would benefit from multi-year funding as many of the items above will extend across fiscal-year boundaries and so it is recommended that the potential benefits of multi-year funding be assessed and identified.

(5) Brad Williams noted that NE is currently developing a Strategic Plan that will ensure integration of the VTR project in NE-4 scope and the Advanced Reactor Development activities of NE-5. The Subcommittee endorses this integration strategy.

The Subcommittee would like to have regular program updates on progress of the VTR Project and especially updates on the itemized topics (1) – (5) above.

IX. Fast Reactor Metallic Fuels

The Subcommittee heard a R&D Update presentation on Metallic Fuels for Fast Reactors by the National Technical Director of the Advanced Fuels Campaign, whose two missions are to support development of near-term ATF for LWRs and to perform R&D on long-term advanced reactor fuel. The presentation dedicated to the second point provided a background on historic features of metallic fuels, a description of ongoing fuel fabrication developments and of fuel alloy additive studies, and recent results of the Irradiation Testing Program of metallic fuels in ATR. Of particular interest was the point on the second generation metallic fuel developed for the Versatile Test Reactor.

Metallic fuels based on U-Pu-Zr alloy have inherent thermo-physical properties which allow their well-known good benefits in terms of (1) remote compact fabrication processes, (2) reliability to a burnup of up to 20 at%, and (3) passive approach to reactor safety thanks to low-swelling cladding and Na bond in fuel-cladding gap allowing low fuel temperature. Still these properties have to be improved for advanced reactors applications; in particular, the VTR, TerraPower reactor or micro-reactors may have to use Na-free, annular metallic fuel concepts with very high burnup, up to possibly 40 at%. Fuels for high temperature fast spectrum reactors will need high cladding temperature/performance and may incorporate additives or cladding coatings to limit fuel-cladding chemical interaction (FCCI).

Fabrication developments pursue the objectives of producing these advanced fuels with process simplification and optimization, especially to reduce fuel losses, high level wastes and crucible cleaning and coating during fabrication operations. Innovative remote casting of U-TRU-RE-Zr possibly using zirconium sheaths has been successfully demonstrated recently in the Hot Fuel Examination Facility (HFEF) with a rapid cycle time and advanced crucible. The extrusion process is also undergoing laboratory development with some demonstration tests for producing annular pellets with an integral Zr liner, since usual casting is not suited for producing annular pellets.

One main issue regarding the behavior of in-pile metallic fuel is the fuel-cladding chemical interaction, mainly due to the lanthanide fission products which migrate to the fuel surface and interact with the stainless steel cladding. The use of minor palladium additions in the fuel has been largely tested in the past, in order to form Ln-Pd which efficiently mitigates the FFCI during irradiation. Still, palladium reacts with Zr during the fresh fuel casting process and is no more liberated during irradiation which limits strongly its positive FFCI effect. More recent studies have been carried out by using tin (Sn) instead of Pd as an additive for FFCI control; it is worth noting that these early promising results have to be clearly confirmed in the future.

Beginning in 2003, the Advanced Fuel Campaign has developed an important irradiation testing program in ATR, using Cadmium-shrouded systems, which provide some confidence with respect to prototypic fast neutron irradiation conditions. Fast and thermal irradiation conditions have been compared by INL and a peer review of independent external experts on in-pile fuel phenomena. The main conclusions were positive, except for cladding strain. This is a significant accomplishment of the campaign which shows that ATR irradiations with the Cd shroud system is sufficiently prototypic that it can be used to develop fast reactor fuels with confidence. It is also worth noting that qualitative Electron Probe Microanalysis (EPMA) examinations are now operational at the Irradiated Materials Characterization Laboratory. Important key findings were relevant for high Pu (30 wt%) alloys which performed as well as 20 wt% FFTF alloys, and for annular fuels which accommodate swelling without excessive cladding strain upon contact between the metal slug and the cladding on the contrary of full cylindrical geometry. The campaign has also developed the Accelerated Fuel Testing Initiative (FAST) with revised capsule design objectives that could achieve more than 5at% burnup/ATR 55-day cycle and so 30at% burnup in less than 2 years in ATR. The Subcommittee looks forward to hearing more about the progress of this initiative.

First thoughts were presented for the VTR startup fuel design and specifications, and for an advanced second generation driver fuel to be qualified using the VTR. Solid design, 20 wt% Pu, sodium-bonded fuel is the leading candidate for the startup fuel. Annular design, 30 wt% Pu, sodium-free fuel could be a prime candidate for the second generation fuel. It would be instructive to know more in the future about the development plan of this advanced driver fuel.

The advanced fuel development program is to be complemented, especially with the recent PIE findings of the metallic fuel irradiations in ATR. At this stage, we have no recommendations, but observe that changes will eventually be needed within the program. The Subcommittee understands the challenging aspects of making progress in this area, which necessitates a long term determined research effort from fuel fabrication to PIE final results. Most of the activities in the existing program are appropriate and necessary to pursue within the existing policy construct. Beyond ATR test irradiations, it is also of utmost importance to perform transient testing to obtain data on fuel failure mechanisms and failure margins for combinations of fuel, cladding, and burnup for which the current database is deficient. Many codes that model such processes exist and others are under development; however, it will be crucial to validate the codes with experimental tests. In fact, in DOE's Advanced Reactor Fuel Development Program, without such transient tests, new concepts will not be able to pass Technology Readiness Level Six (TRL-6), which involves the study of prototypic rod/compact and assembly/element irradiation in representative fast neutron environments, under the full range of relevant normal and off-normal conditions.

X. ZIRCEX Briefing

The future of nuclear power requires providing a comprehensive fuel cycle for the diversity of reactors in development. Interest in micro-reactor concepts has grown in the past several years, and a number of companies are pursuing novel designs. These reactors may form a bridge between the current fleet and advanced nuclear reactors, or may serve in specialty applications. Most advanced reactors require fuel/cladding systems that differ from those used in traditional light water reactors, which is driving the need for HALEU. NEI has provided estimates for annual commercial requirements for HALEU through 2030, and while it was noted throughout the meeting that these estimates are by nature highly uncertain, they speak to a potential need for a cumulative total of >500 MTU HALEU in this timeframe. As emphasized in the Thursday morning discussion with Mr. McGinnis, there currently is no U.S. domestic enrichment capability to enrich to the 5-20 at% level. This is driving the interest in domestic enrichment capability with a mandate to use U.S. technologies *and* U.S. commercial providers. An interim measure to supply the necessary material to support reactor development is required, possibly through downblending existing highly-enriched uranium (HEU). The 2019 Energy and Water Appropriations conference report provided \$20M specifically for “highly enriched uranium recovery preparation and testing” to meet this demand.

Idaho National Laboratory is piloting the recovery and downblending of HEU from several “end-of-life” fuels previously intended for disposition, including EBR-II fuel, ATR fuel, and Naval Reactor fuel. Among the processes being developed is a modification of the ZIRCEX process, originally developed in the 1960s for the separation of uranium from U-Zr alloys. In this implementation of the ZIRCEX process, zirconium or aluminum cladding is removed through a dry chlorination step to produce volatile $ZrCl_4$ or $AlCl_3$. Uranium is then recovered in a compact, modular solvent extraction system, and downblended. Waste treatment includes immobilization of fission products in glass. It is anticipated that high level waste will meet WIPP waste acceptance criteria and be accepted as a product of DOE R&D. This hybrid process has the advantage over past methods of not requiring complete dissolution of the fuel element, reducing waste, and increasing throughput. Lab-scale chlorination experiments have been demonstrated on unirradiated Zircaloy and small irradiated fuel samples. Studies on scaling up the process are mandatory (especially for the treatment of old irradiated fuels likely to have very specific properties after long storage periods), and the next step is demonstration of the process at the pilot scale with unirradiated fuel. A 6-inch fluidized bed size scale facility was chosen for the chlorination reaction to stay within criticality safety limits. A number of factors remain to be investigated in this pilot scale testing, including process control, corrosion studies, and understanding the potential for fission product loss through carryover with zirconium. The current schedule should permit testing with unirradiated fuel in the pilot facility by the fall of 2019. Additional work is targeting the development of the aqueous extraction step, waste vitrification, and downblending schemes.

A long-term schedule is projected incorporating demonstration in the pilot plant (into 2021), followed by design, construction, and operation (commencing in 2025) of a full-scale facility. A facility options study is in process.

To meet shorter-term needs, existing stores of HALEU can now be used. Since 2000, DOE has used an electrochemical separation in a batch process to separate, recover, and downblend uranium from EBR-II fuel. A recent DOE environmental assessment produced a Finding of No Significant Impact (FONSI) for a proposed action to use this material (several metric tons) currently in storage. The process will continue to be operated for approximately ten years (with a current capacity of 0.4 MT/yr, with possible higher production rates).

There are several sources of uncertainty in understanding future needs and availability of HALEU. Given the importance of the existing development of the various concepts for innovative reactors needing

domestic HALEU, some anticipation of this enrichment program would have been helpful. In this sense, the timing of demonstration/production collectively between these processes now exercised at INL has to be clearly specified. There is also likely uncertainty associated with future willingness and ability for commercial entities to undertake enrichment and/or recovery operations (it was stressed that DOE intends this as a demonstration and bridge to future enrichment options). Other challenges remain, including the concern that no certified shipping containers exist for HALEU. Significant hurdles still exist in meeting future projected needs for HALEU. Given the converging interests in defense and civilian uranium enrichment, as evidenced in appropriations language, it would be instructive to know what synergy exists in RD&D efforts within the Department of Energy.

XI. NEUP and User Facilities Update

Since FY09, NE has designated up to 20 percent of the funds appropriated to its R&D programs be applied to university-led R&D and associated infrastructure projects. These R&D projects are awarded through an open, competitive solicitations process, which is managed by the Nuclear Energy University Program (NEUP).

- **Research & Development:** projects that focus on the more general and longer-term needs of the NE R&D programs.
- **Integrated Research Projects:** large collaborative projects that address significant near-term needs of the NE R&D programs.
- **Infrastructure:** improvements that further the R&D and educational missions of universities, to include upgrades to university research reactors and general scientific infrastructure purchases.

The nuclear science and engineering community finds it is essential to maintain robust U.S. university participation in nuclear energy R&D because our universities are often best positioned to provide some of the innovative and transformative approaches necessary to fill current technology and knowledge gaps that must be addressed for the nation to meet its long-term energy needs.

NEUP R&D awards have been made to over 100 U.S. universities as project leads. These R&D awards have also supported 1,716 students (716 PhD, 599 Masters and 401 Undergraduate degrees) since 2009. Sixty U.S. universities have received General Scientific Infrastructure grants to improve lab equipment and capabilities and all 25 U.S. university research reactors have been funded for reactor improvements through the Infrastructure Reactor Upgrade program.

It is notable that the NEUP awards have broadened the engagement of the DOE with more universities than in the past, particularly through awards to teams of institutions. Such expansion of engagement is important to diversification of the talent pipeline. The DOE, national laboratories, and nuclear industry all face a significant demographic challenge since a large fraction of staff is now or soon will be eligible for retirement. Diversification of the talent pipeline is important to meeting the need for quality staff development throughout the nation.

Through NEUP and collaborating programs, DOE-NE has awarded over \$637 million in lead institution awards to 123 U.S. universities, 7 national laboratories, and 15 industry/utilities in 42 states and the District of Columbia since 2009; i.e., an average of \$64 million each year. These projects span the full spectrum of nuclear energy research, including the development of advanced reactor concepts to improve competitiveness and meet the nation's energy needs, development and analysis of technologies to ensure a sustainable nuclear fuel cycle, and advanced modeling and simulation methods to better understand nuclear reactor and fuel system behavior. NEUP projects have resulted in more

than 1,250 journal publications, conference presentations, and book chapters that have been cited more than 10,000 times in other scholarly works. This represents over 50% of all the peer-reviewed journal publications and citations related to nuclear engineering from all of DOE-NE R&D activities.

The FY19 Consolidated Innovative Nuclear Research (CINR) R&D and University Infrastructure Funding Opportunity Announcements (FOA) were issued in September 2018. Since the release of the FOAs, a number of NE program priority shifts requiring funding reallocations occurred, resulting in various impacts to NE's ability to execute the FY19 CINR R&D and University Infrastructure FOAs as originally planned. Specifically, funding for the new priorities required NE to cancel four fuel cycle (FC) and three Integrated Research Project (IRP) technical workscopes included in the CINR R&D FOA. In January 2019, NE announced consolidation of its research portfolio to ensure investments would be fully aligned with its highest priorities supporting the accelerated development of critical advanced reactor technology in the U.S. Principal Investigators (PI) who submitted pre-applications (20 total PIs from 14 universities) to the four cancelled FC workscopes were notified that the workscopes would not be funded due to the program priority shifts. These notifications caused significant concern and raised questions in the university community. This action is at odds with countless recommendations noting that the strength of the U.S. university system is one of our nation's greatest strengths for nuclear energy's sustainability and innovation, and recognizing that NEUP underpins those strengths. Explanation of the NE program priority shifts emerged during the Fuel Cycle and Infrastructure Subcommittee meeting when we were informed that the NEUP portion of the Nuclear Fuel Cycle budget was being reduced by \$23M for FY19, i.e., from \$31.5M in FY18 to \$10.6M in FY19. The program priority shift determined that these funds were needed to support a \$30M increase in the Civil Nuclear Enrichment budget to support the first year of a new centrifuge enrichment demonstration project devoted to HALEU. We are extremely concerned not only with the cuts, but with the process that led to them.

Recommendation:

Persistent and balanced support for university research funding is essential to sustaining our technological edge and maintaining our leadership in the global community, in addition to educating and preparing the future workforce of nuclear engineers. We strongly recommend that NE reexamine its method of dealing with such short-term budget issues and not single out and penalize the NEUP disproportionately. The NEUP should be restored to its historic 20% of NE R&D funds.

Nuclear Science User Facilities (NSUF)

In 2007, NE established the NSUF. Launched at Idaho National Laboratory (INL), the NSUF was initially intended as a single institution user facility with a focus on irradiation effects in nuclear fuels and on reactor materials. This vision for a one-stop, nuclear-related characterization facility broke down rather quickly when it was realized that not every characterization method could or should move to INL. Today, NSUF involves INL and 20 partner institutions that include facilities from 11 universities, 7 National Laboratories, the Center for Advanced Energy Studies (that include 4 additional universities), and 1 industry partner. The NSUF also maintains the searchable NE Infrastructure Database (NEID) as part of its Infrastructure Management Program where approximately 150 institutions that operate roughly 500 facilities housing ~1000 instruments (80% domestic and 20% international) of potential interest to the nuclear researcher community are catalogued. The NEID is easily accessed through the NSUF website (nsuf.inl.gov). With one key exception, NSUF operates like a typical national user facility, i.e., there is no cost to the user, there is a competitive, peer-reviewed proposal process for user access, and NSUF funding is not allocated directly to the user, but provided to the facility for the approved user experimental access. Projects can span several years or be of short duration. Users, of course, may be

funded from other NE sources such as NEUP, IRP, etc. The key difference between NSUF and other national user facilities is that there is no funding provided to the facilities from NSUF for base support of the facility. The assumption is that the instrument or capability and attendant upgrades and/or replacements are funded by some other mechanism. This has led to the NSUF Director's catch phrase, "pay by the drink."

NSUF is divided into two components: (1) Consolidated Innovative Nuclear Research (CINR), and (2) Rapid Turnaround Experiments (RTE). There is one call per year for the CINR (primarily multi-year, large scale experiments), and three calls per year for RTE. Proposals are solicited from academia, national laboratories, industry and small businesses. Only non-proprietary research projects are funded and all awards are fully forward funded. The NSUF Director showed the Subcommittee a multi-year bar chart that indicated the interest in and funding for the NSUF CINR program. In FY10, the CINR budget was ~\$6M. By FY18, the budget had grown to \$10M. Also, in 2018, there were 71 CINR pre-applications, 21 full applications, and 9 awards. In 2018, there were 280 RTE applications and 105 awards. The RTE funding was not provided at the meeting. NSUF also maintains a Nuclear Fuels and Materials Library (NFML), a NE Expertise Database (NEED), a Projects database, and offers Database Integration via the Combined Materials Experiment Toolkit (CoMET).

The Subcommittee's observation is that NSUF is a well-run program that is under-funded given the obvious demand for instrument and reactor time. When pressed for a wish list, the Director stated a fast neutron irradiation capability and access for higher activity experiments at x-ray light sources such as the Advanced Photon Source (APS). The Subcommittee noted that there are examples, e.g., Stanford Synchrotron Radiation Lightsource (SSRL), where such experiments are possible, and encouraged the Director to visit these facilities. However, we observe that such a radiation capability takes several years to put in place as well as the concerted efforts of passionate and dedicated researchers, not to mention the cost of building and maintaining a beamline.

Recommendation:

The NSUF program has been in existence for over a decade. The Subcommittee recommends that NE-5 convene a high-level committee comprised of nuclear scientists and engineers from academia, national laboratories and industry with the following charge:

- (1) Assess the current suite of NSUF capabilities to interrogate/examine fuels and irradiated materials.
- (2) Analyze the usage and productivity of current NSUF sites.
- (3) Evaluate how well the NSUF enterprise is serving its users.
- (4) Make recommendations for developing a process to make capital investments in the most needed upgrades to the facility as well as its associated instrumentation and testing capabilities. Consideration should be given to partnering with other parts of the Department.