Draft Minutes
Nuclear Energy Advisory Committee
June 5, 2014
Marriott Hotel at Metro Center
Washington, D.C.

Committee Members Participating:

Ashok Bhatnagar (via telephone)
Dana Christensen
Matthew Bunn
Michael Corradini (via telephone)
Susan Eisenhower, Cochair
Donald Hintz
Susan Ion
Raymond Juzaitis
Mujid Kazimi
William Martin
Regis Matzie
Richard Meserve, Cochair
Warren Pete Miller
Carl Paperiello
Joy Rempe
Alfred Sattelberger

Committee Members Absent:

None

Other Participants:

Erica Bickford, AAAS Fellow, Office of Nuclear Energy, USDOE
Alice Caponiti, Director for Space and Defense Power Systems, Office of Nuclear Energy, USDOE
Nancy Carder, NEAC Support Staff, Medical University of South Carolina
Joyce Connery, Director, Nuclear Energy Policy, Office of International Economics, National Security Council
John Herczeg, Associate Deputy Assistant Secretary, Fuel Cycle Technologies, Office of Nuclear Energy, USDOE
Alexander Larzelere, Program Manager, Modeling and Simulation Energy Innovation Hub, Office of Nuclear Energy, USDOE
Peter Lyons, Assistant Secretary, Office of Nuclear Energy, USDOE
Edward McGinnis, Deputy Assistant Secretary, International Nuclear Energy Policy and Cooperation, Office of Nuclear Energy, USDOE
Frederick O'Hara, NEAC Recording Secretary, Medical University of South Carolina
Monica Regalbuto, Deputy Assistant Secretary for Fuel Cycle Technologies, Office of Nuclear Energy, USDOE
Gary Rochau, Manager, Advanced Nuclear Concepts, Sandia National Laboratories
Robert Rova, NEAC Designated Federal Officer, Office of Nuclear Energy, USDOE
Michael Schmidt, NEAC Support Staff, Medical University of South Carolina
Marius Stan, Senior Advisor, Office of Nuclear Energy, USDOE
Roald Wigeland, Nuclear Science and Technology, Idaho National Laboratory

About 35 others were in attendance in the course of the meeting.

Morning Session

Before the meeting, **Wayne Gordon**, DOE General Counsel's Office, presented an ethics briefing for the Committee members.

The meeting was called to order at 9:03 a.m. by Cochair **Richard Meserve**. **Peter Lyons** greeted the members and thanked them for their service. **Robert Rova** made safety and convenience announcements.

Peter Lyons gave an overview of the activities of the Office of Nuclear Energy (NE).

The President has nominated Monica Regalbuto as the Assistant Secretary of Energy for Environmental Management.

NE continues to have the full confidence of the President, who said in his State of the Union Address, "climate change is a fact. And when our children's children look us in the eye and ask if we did all we could to leave them a safer, more stable world, with new sources of energy, I want to be able to say yes, we did." Secretary Moniz is outspoken on climate change and the President's energy agenda and has spoken on the importance of nuclear power, emphasizing the role of small modular reactors (SMRs) in the nation's energy future.

Michael Simpson is taking over the leadership of the House Energy and Water Subcommittee. The FY14 request for NE was $735 million; the amount enacted was $888 million. The FY15 request was $863 million. Of that, $97 million is for the continued technical support for licensing two SMRs; $101 million is for expanding light-water-reactor sustainability efforts to maintain carbon-free generation by the current fleet of nuclear reactors and supporting the development of non-water-cooled reactor systems; $78 million is for the Energy-Innovation Hub modeling and simulation; $189 million reflects a strong interest in commercial used-nuclear-fuel disposal solutions, looking at all options for waste storage; $28 million is to accelerate commercialization of supercritical CO_2 Brayton-cycle energy-conversion technologies with a 10-MWe demonstration project of interest to multiple DOE offices (NE has been given the lead); and $290 million is for Idaho National Laboratory (INL), which remains critical to NE's activities and for which NE is the steward. In response to a question from Miller, it was noted that INL's safety and security and operations are funded separately within the NE budget.

Areas of strong Congressional interest were the Integrated University Program, the SMR licensing technical support, and Idaho facilities management. Thermoelectric generator work was shifted to the National Aeronautics and Space Administration (NASA).

Ion asked if the NE University Program (NEUP) would show up somewhere else. Lyons replied that the scholarship and fellowships are being shifted to another agency. Research grants will continue to be made by NE and will continue to be funded up front.

The $6.5 billion Vogtle loan guarantee was announced. It is a strong indicator of this administration's support of nuclear power.

The Rothwell and Ganda report on *Electricity Generating Portfolios with Small Modular Reactors* was issued. It presents a business model to show how portfolio risk changes as the diversity of energy sources increases. Today, one can get the lowest levelized cost for energy with a portfolio that is 100% natural gas. Fuel-price volatility and uncertainty produce risk, though. The addition of SMRs increases the levelized cost but significantly drives down the portfolio risk because of lower fuel-cost volatility. Eisenhower asked if this report would be available to the public. Lyons replied, yes. This report is the first time that the risk level has been quantified in light of portfolio fuel-source diversity. Bunn asked if renewables were included. Lyons believed that the study was of all baseload sources. Matzie noted that, about 15 years ago, the Electric Power Research Institute (EPRI) showed that a diverse portfolio lowered risk. Lyons suggested that Matthew Crozat might be a good speaker at the next NEAC meeting. Meserve asked whether full-scale reactors would give the same results as for SMRs. Lyons replied that they would but only in certain markets and for certain large utilities.

In the program for technical support in licensing of SMRs, B&W mPower America was the winner of the first funding opportunity announcement (FOA) in April 2013. This is a cooperative effort among Babcock and Wilcox, Bechtel, and the Tennessee Valley Authority (TVA), with an initial DOE commitment of $101 million through March 2014. NuScale Power was the winner of the second FOA, which was announced on December 12, 2013. A cooperative agreement was signed May 27, 2014, with DOE funding up to $217 million for NuScale SMR development. In the NuScale design, there are no pumps to fail, providing maximum safety.

The INL contract was renewed with Energy Alliance for an additional 5 years. This is a strong step forward.

In the process of resuming transient testing, an environmental assessment with a finding of no significant impact was issued in February 2014; it identified the Transient Reactor Test Facility (TREAT)

at INL as the preferred alternative for transient testing. The aim is to resume transient testing operations by FY18 for the testing of accident-tolerant fuels. Miller asked how much support INL got from EERE and other offices and agencies. Lyons replied that it was a significant amount. There has been a lot of discussion of the fuel for TREAT, and the world is moving beyond highly enriched uranium fuels. The fuel choice is a "forever" situation because one does not use much fuel in a transient test.

The Energy Innovation Laboratory at INL supports the clean-energy research of the Office of Energy Efficiency and Renewable Energy (EERE) and the development of new materials for advanced nuclear reactors by NE. This facility continues the evolution of INL. The Irradiated Materials Characterization Laboratory at INL is designed to house post-irradiation examination equipment to support a broad range of research on irradiated fuels and highly activated materials. This will be an extremely important facility going forward and an important complement to other INL facilities. It includes state-of-the-art instrumentation.

The courts ordered the completion of the Yucca Mountain licensing activities. On February 28, DOE advised the Nuclear Regulatory Commission (NRC) that it would provide an updated version of the July 2000 Technical Report to provide the NRC with substantially all the technical information necessary to create a draft groundwater supplemental environmental impact statement.

In modeling and simulation, the Consortium for Advanced Simulation of Light Water Reactors (CASL) focuses on moving supercomputing into industry, and Nuclear Energy Advanced Modeling and Simulation (NEAMS) develops codes to go into CASL. A talk later in this meeting focuses on how NE is making NEAMS even more responsive to CASL's needs.

NE has agreed to sponsor a study of hybrid energy systems. The study will examine optimizing clean-energy sources (intermittent and baseload) to produce clean-energy products. One idea to be examined is the constant running of a nuclear power plant at full power; when demand is satisfied, the rest of the generation is stored for future use. How to take the best advantages of different clean-energy sources will be looked at. A kickoff workshop will occur July 8–10 at INL; it will include academia, industry, and international participants. Baseload and intermittent generation will be compared to see how they can work together along with carbon capture.

NE's Nuclear Energy University Programs continue to be very strong. The program is coordinated with similar programs in other countries. NE *should* provide scholarships and fellowships, but there is a diversity of opinion on this policy. NE is awarding $16 million per year for construction and scholarship grants.

There is a strong demand for nuclear energy around the world. The AP1000 is a tremendous success of the NP 2010 program. Perhaps in the future, someone will talk about the DOE support for launching SMRs.

Martin asked why, with all the models and simulations, one cannot get all the economic externalities of nuclear power correct. Why cannot one consider those externalities? Lyons replied that there are many models that can input those externalities, but what those values should be is very controversial. The issue is getting people to agree on the values of the externalities. How to set those values is still under consideration. For example, should there be a value assigned to responsiveness in upset conditions? Martin stated that one has to have an agreed-to methodology, and then one could wage a fair war. A debate is needed on how to value the externalities. Lyons rejoined that, when politics invades the discussion, there is difficulty making any progress. Hintz asserted that members of the Department of Energy would be the best ones to value those externalities. A range of values should be set for nuclear power, clean energy, etc. At the present time, utilities are just going to build natural-gas-fired plants; those plants produce the largest returns in the short run. Nothing will happen if the nation does not do what Martin says. Lyons referred to the EPRI studies on seven different plans for reducing CO_2. Those studies said that CO_2 cannot be reduced without nuclear power. The state of California studies said the same thing. Martin pointed out that consistency is needed; it is a methodological issue. Lyons replied that that is what the *Quadrennial Energy Review* is supposed to do. Bunn pointed out that the administration had set a value of $30 per ton of CO_2, but there are other significant players that do not accept that value.

Fine particulates from coal plants are another major externality. Studies show that the economic cost from particulates is major.

Gary Rochau was introduced to speak about the supercritical CO_2 Brayton cycle as an advanced-energy project.

In the Brayton cycle, supercritical CO_2 remains in a single phase throughout the process, unlike water in the traditional Rankine steam cycle, leading to greater energy-conversion efficiency. At operating temperatures, supercritical CO2 has high enthalpies and physical densities greater than steam, which reduces the volume of working fluid and the overall system size by an order of magnitude, subsequently reducing capital cost. It recycles heat not used in electricity production. It also increases efficiency by as much as 50% and reduces the cost of electricity production. It reduces greenhouse-gas production, reduces water consumption, and allows dry cooling. It does have challenges: existing components and materials may not be suitable, a wide range of operating parameters and applications would need to be accommodated, existing technologies would need to be integrated and scaled up, and robust operating procedures for operating at the critical point would need to be developed.

While a typical efficiency of a Rankine cycle is 33%, a supercritical CO_2 Brayton cycle could surpass 40% efficiency, depending on temperatures. A 300-MWe Rankine-cycle steam turbine is 20 m long; a comparable Brayton cycle supercritical CO_2 turbine would be 1 m long.

NE started looking at this technology to develop improvements in the affordability of new reactors to enable nuclear energy to help meet the Administration's energy-security and climate-change goals. The Office is maturing this technology to promote the Administration's clean-energy strategy. Supercritical CO_2 was chosen because CO_2 is much less reactive with sodium and can remove heat from a reactor very efficiently. This technology has been employed in other applications for years. Higher efficiencies are obtained at higher temperatures and higher pressures, but such applications push the material requirements. The pathway to high conversion efficiency calls for temperatures from 600 to 800 °C with CO_2, a recompression closed Brayton cycle (RCBC), reheat, and intercooling.

Test articles 12 inches in diameter and 24 inches long are being operated in the laboratory. How to handle supercritical fluids is a major research objective. Special steels and bearings are needed. The research is designed to verify cycle performance versus theory, developed cycle controls, and develop maintenance procedures. The design is export controlled. Bearings float on gas cushions. The device has to run at a high speed because of the dynamics of the turbine. Increasing the power level decreases the shaft speed. Experimental machines show increases in gross efficiency with increasing temperature that are parallel to the theoretically projected increases. The efficiency of the current test articles is to be increased by eliminating seal leakage and windage, insulating against heat losses, increasing the pressure ratio, developing second-generation turbomachinery that is not on the same shaft, and optimizing the system.

An advanced SMR energy-conversion heat exchanger is under development. These systems employ fusion-bonded heat exchangers. A factor-of-2 reduction in cost has been demonstrated, and a factor-of-10 reduction is projected.

The goals are

- commercializing a system scalable to 1000 MWe with $30 to 40 million in funding,
- placing a stronger emphasis on industry collaboration through cooperative agreements to provide equipment-infrastructure resources, and
- improving the technology readiness and moving toward a demonstration capable of "power on the grid" by 2019.

The system has to operate reliably for a long term and would be used as a pilot system after the demonstration. Success would be defined as commercial production of such systems. Grid synchronization could occur with a 300-MWe machine.

High-temperature materials are needed. The goal is a high-nickel supercritical-CO_2-corrosion-resistant alloy formed into a large-diameter pipe that can handle 850 °C at 30 MPa. Current costs for such materials are prohibitive, years of lead time are required, the current temperature limit on such materials is 650 °C, and 700 °C service would require code certification. Advanced heat exchangers would cost

about $60,000. The turbine, compressor, and power-generation industries are currently being scanned to identify readiness of subsystem components for various Brayton-cycle applications.

In FY14, cost-shared programmatic research will continue in NE, Fossil Energy, and EERE, looking at Brayton-cycle R&D, high-temperature experimental reactors, sodium–CO_2 interactions, modeling, plugging loops, higher efficiencies, material development, carbon sequestration, solar applications, and effects of supercritical CO_2 on materials. A technology team has been chartered, a request for information for program support has been issued, and a workshop will be held on June 23, 2014.

Lyons stated that this is transformational technology. This is also a joint effort among multiple DOE offices and affects five other DOE offices, thus minimizing the use of funding resources.

Meserve asked whether industry would use this technology. Rochau answered that General Electric is interested in it if there are not the corrosion issues that they have had to deal with with supercritical steam. Small size is attractive because it reduces costs. DOE is also engaged with turbine manufacturers. An industry workshop is being held to look at markets and what needs to be done.

Bunn noted that the community had been looking at helium for use in high-temperature energy production and asked what the difference was between supercritical CO_2 and helium. Rochau replied that CO_2 is a larger molecule and does not leak as readily. It is the most cost-effective way to get the energy.

Ion asked if, given current commercialization efforts, one should go directly to the manufacturers of the small modular reactors. Rochau responded that it gets down to the economics and operating temperatures of the SMRs.

Matzie pointed out that the development path is very long, especially as one scales up. An important aspect here is the applicability to a variety of systems from solar to nuclear. Industry must be fully engaged in the development and have skin in the game.

Kazimi asked how one would scale from 150 kW to 100,000 kW. Rochau answered that there is no rational argument for the answer. The 150-kW size of the experimental device was chosen because it was a size that DOE could afford to build. The funding amounts to $16 million over 8 years. The compressor designs are available. The turbines seem to be buildable. The scaling is straightforward. The engineering challenge is using a supercritical fluid. Kazimi pointed out that larger pipes may lead to larger leaks; one would want to scale up slowly. Rochau responded that the “prove it” factor has to be dealt with.

A break was declared at 11:04 a.m. The meeting was called back into session at 11:13 a.m.

Marius Stan was introduced to discuss advanced modeling and simulation for nuclear energy.

A model is a logical description of how a system performs. It is empirical (interpolation is based on observation) and it is theory-based (interpretation is also based on theory). Simulation is the process of running computer programs to reproduce in a simplified way the behavior of a system.

In advanced software, application complexity can go from single physics, single scale to multi-physics, multi-scale; and computational complexity can go from low-performance 1-D serial to high-performance 4-D parallel. The scales of the methods that DOE is using go from atomistic to mesoscale to the continuum. The methods themselves include density functional theory (DFT), molecular dynamics, kinetic Monte Carlo, phase-fueled, thermochemistry and mean-field, dislocation dynamics, and finite-element methods among others.

CASL provides strength and feedback, and NEAMS provides tools. Coordination between CASL and NEAMS improves advanced multi-physics computational methods, accelerates innovation, and avoids duplication of efforts.

Miller asked what the funding status of CASL was. Stan replied that it is up for review and renewal. Lyons added that the funding is awaiting Congressional approval.

The funding for NEAMS has gone from $7.8 million in FY08 to $21.5 million in FY15. The funding for CASL has gone from $22 million in FY10 to $24.3 million in FY15.

NEAMS has two product lines: the fuels product line and the reactors product line. The fuels product line goes from microstructure to the fuel elements; the MOOSE-BISON-MARMOT toolset provides advanced, multi-scale fuel-performance capability. The reactors product line goes from the reactor core to the full plant and seeks to model seamless interoperability with robust products that follow the traditional workflow but position the toolkit for future approaches.

In early 2014, program participants were surveyed about NEAMS and its interaction with CASL. The survey indicated that the quality of the NEAMS software is very good, that NEAMS is technology-versatile, and that NEAMS must solve a problem. The same survey indicated that CASL is focused, has synergy, and exhibits stability. NEAMS was credited with participating in problem definition, leading the scientific and engineering approach, and demonstrating high-impact benefits while the customer states the high-impact level of the problem, provides technical support and validation data, and certifies the high-impact effect. NEAMS has a national technical director who is guided by the NEAMS Leadership Council.

NEAMS has developed a new model for the average grain size in uranium oxide fuel using atomistic and mesoscale simulations. Simulation showed how small changes in unit dimensions (here, inlet size) changed the unit's performance (here, mixing).

CASL has developed the Virtual Environment for Reactor Applications (VERA), its evolving virtual reactor for in-vessel light-water-reactor (LWR) phenomena. VERA has been used to analyze the thermal flux profile of the Watts Bar Unit One reactor at hot full power. This is a highly complex simulation with more than 1,000,000,000 degrees of freedom. The simulation ran for 14.5 hours on the Titan computer using 18,769 cores; more than 1 million unique material regions were resolved. The next steps in the simulation will be to add fuel depletion and core shuffling and then compare results to plant-measured data.

The Center for Materials Science of Nuclear Fuels is focused on understanding the effects of microstructure on thermal transport in irradiated nuclear fuels. It has measured thermal transport at different phonon branches to understand thermal transport at the phonon level. The 5f-electron problem in DFT causes the discrepancy observed. This is a good example of using experiments to validate modeling.

The Center for Exascale Simulation of Advanced Reactors works with industry and DOE research partners to influence the design of future hardware architecture, system software, and applications on the basis of key algorithms that underlie computational nuclear engineering. It is developing a new generation of algorithms that enable the solution of significant, outstanding nuclear-engineering problems by leveraging exascale resources.

Kazimi asked if there were any external eyes looking at the product. Stan replied, no. There are internal review processes that are vested in the program.

Juzaitis asked if there were a way to express the metric for showing that simulations are better bounded. Stan answered that validation must be achieved by experimentation. Others use analytical solutions or benchmarking against other codes that have been validated.

Bunn pointed out that one could make a better case for simulation if there were examples of industry adoption. Larzelere said that those adoptions are coming out in the literature. Westinghouse is using CASL on the AP1000 and getting good results, speeding up the design and construction of future reactors. Industry is packaging up and using CASL tools in a short time.

Rempe asked if regulators were accepting these efforts and participating. Larzelere said that the CASL staff meets with the Nuclear Regulatory Commission (NRC) every 6 months. The NRC recognizes that codes make possible better ways to design reactors.

Miller noted that, in 2009, Secretary Chu announced the hubs, and NE decided to look at an LWR that would be useful to the industry. That decision was made at the insistence of Peter Lyons.

Erika Bickford was introduced to present a demonstration of the Stakeholder Tool for Assessing Radioactive Transportation (START).

She reviewed the features that the tool mapped and described and she ran through a sample analysis, showing and characterizing the transport of spent nuclear fuel from the San Onofre Nuclear Generating Station to Madison, Wisconsin.

The purpose of the START software is to provide a decision-support tool for NE's spent-fuel transportation planning. It looks at different modes of transport, transport routes, and transportation-emergency preparedness.

It must cover the entire continental United States; represent the physical and operating characteristics of freight surface-transportation modes; include relevant proximate features of the landscape; be web

accessible in a secure manner; support functionality, feature, and data updates; and leverage geographic information system technology.

A study of existing tools was undertaken to review their capabilities. The study found that none of the existing tools were capable of fulfilling DOE's needs without major overhaul at significant expense. The recommendation was made to develop a new tool to leverage advances made in information technologies. The Esri [Environmental Systems Research Institute] ArcGIS was adopted as the tool-development platform. The tool was designed to analyze alternative routing criteria, include detailed transportation-system attributes, provide emergency-response information, include radiological-risk estimates on the front end, provide an integrated system that would enable the user to get the whole story, and offer an intuitive menu structure consistent with stakeholder needs. START supports the development of a transportation plan, the route-selection process and preliminary routing-analysis activities, radiation-accident training and support, data-collection activities at shut-down sites, and coordination with waste-management data and systems-integration tool-development initiatives.

The tool is currently in the beta-testing stage. Program modifications and upgrades are being made on the basis of data-test feedback. A user manual is being prepared. Case studies are being performed to illustrate how START can be used to support stakeholder needs. A project rollout is being planned that will offer credentialing, training sessions, conference presentations, and workshops.

Meserve suggested discussing the topic of casks with the NRC and identifying areas (federal, state, and local) that exclude the transportation of radioactive materials.

Paperiello suggested building in the flexibility to analyze the shipping of materials for the front end of the fuel cycle and to analyze radiation risk. Bickford agreed that those additions would be good.

Eisenhower asked (1) about plans for credentialing and (2) if the military had been putting together a similar tool. Bickford replied that the system had been demonstrated to Naval Reactors; they have not had a need for such a tool, and they do not have the same state-federal interactions. Credentials will go to those who will oversee transport and training for emergency response.

Paperiello asked whether this program calculates a quantitative risk level. Bickford responded that it could in the future but does not now. Paperiello asked if this program could be generalized to other hazardous materials. Bickford responded that it certainly could.

Christensen asked whether the program will incorporate U.S. fuels that are located overseas. Bickford responded, no; that capability not planned for at this point.

Bunn asked if there would also be a measure of destruction risk (e.g., the possibility of economic damage) and whether the program was also looking at diversion of security forces (e.g., seeking and getting security help from nearby military bases). Bickford answered that that capability could be added in; one would need access to the military's data.

Connery stated that DOE should discuss this program with the National Nuclear Security Administration (NNSA). Bickford responded that it has been shown to many people, including NNSA. Regalbuto added that this effort is mainly directed to emergency responders. One would want to add locational data on industrial capacity. Bickford pointed out that Native American tribes have sacred areas that might need to be taken into consideration, also.

A break for lunch was declared at 12:23 p.m.

Afternoon Session

The meeting was called back into session by Co-Chair **Susan Eisenhower** at 1:27 p.m.

Dana Christensen was asked to present the International Subcommittee Report.

The situation is that NE has limited resources to expand its program, and Congressional forecasts indicate that budgets will be flat, at best, for the foreseeable future. As a result, NE must find mechanisms to increase its impact. Increased integration of national-laboratory and university activities could provide the opportunity to increase the value of funds spent.

Mission imperatives that NE must pay attention to the current commercial fleet (industry relationships). It must assure that nuclear energy is available in the future to address the U.S. economy

(e.g., with new and safer designs). And it must assure that the future workforce is available through relationships between universities and national laboratories.

A managers meeting was held on the topic of mission approach. The NE implementation strategy appears to be engineering-driven, to have a solid scientific foundation, to have a flexible experimental framework, to conduct experimental activities efficiently, and to employ a focused application of modeling and simulation supported by quality validation and verification (V&V).

The Subcommittee made a series of observations:

1. The Advanced Test Reactor–Nuclear Scientific User Facilities (ATR–NSUF) began as a pilot in 2007 and has been deemed to be a success. It is recommended that its scope be expanded beyond just materials to include such topics as thermal hydraulics, code development to include V&V, advanced fuels, fuel cycles, and nuclear engineering in the broadest terms.
2. The NSUF, a revised name, would comprise a virtual fleet of user facilities.
3. It would identify all critical facilities across the complex of importance to NE missions and would develop an integrated user-facility framework. It would include hot cells, post-irradiation examination, and nuclear critical experiments.
4. A new model for NSUF should be prominent in the next DOE-NE roadmap. That roadmap should encourage student and faculty use of facilities in NE science R&D; increase industry engagement in cooperative R&D (assuring a focus on important industry needs); and envision next-generation reactors, fuels, fuel cycles, etc. A user organization needs to be established. Integration across programs will overcome any double jeopardy between NSUF and NEUP.
5. High-performance computing is an essential dimension for a successful NE future. The value proposition for CASL needs to be articulated. NEAMs must focus on developing insights into performance and safety for both current and new systems: this provides guidance for experimentation. Experimental facilities must provide validation and verification of new codes.

In closing, the Subcommittee recommends leveraging the success of the original NSUF to build a model of multiple new user facilities. Strong industry engagement is essential; a closer relationship is deemed necessary. Strong university engagement is also essential; NEUP must become an effective aspect of industry engagement. INL's relationships with both industry and universities must be secure and thriving. NE plays many roles with the responsibility to ensure that nuclear energy is available as a candidate energy source to the nation’s economy. The new R&D roadmap must clearly articulate these multiple roles.

Juzaitis asked if there were any agreement on the capitalization and maintenance of the facilities that fall under the NSUF umbrella. Corradini gave the example of a university reactor; in this case, the university would maintain the reactor, perhaps with DOE support, and the NUSF would pick up the experiment’s costs. There is a philosophy here that the tone is integration across topical areas; all three parties should be a party to each discussion. Rempe added that there are other facilities that are affiliated with the ATR facility. Corradini said that industry representatives said that they would volunteer the use of their facilities if they were included in the discussions.

William Martin, the former chair of the International Subcommittee, noted that the scope of that Subcommittee is broad and largely undefined. He introduced **Regis Matzie** to present the report of the Subcommittee.

The NEAC International Subcommittee was charged to determine how to use limited program resources most effectively, how to advance commercially based comprehensive fuel services, and how to support U.S. nuclear exports and overall U.S. international nuclear commercial leadership most effectively as part of a Team USA approach. In considering these charges, the Subcommittee has made a series of observations:

- Observation 1: The United States should team with other countries to advance the once-through approach in fuel-cycle selection. This decision is in agreement with the Blue Ribbon Commission recommendations.
- Observation 2: The United States needs to keep abreast with what other countries are doing to close the nuclear fuel cycle.

- Observation 3: The United States still has intellectual assets. It should develop a catalog of training that could be offered to countries that are new entrants to the nuclear enterprise. The cost of such training would be borne by the profiting industry.
- Observation 4: New emerging nations need to develop infrastructure for safety and security. The United States should help develop that infrastructure including safety culture, nuclear regulatory framework, codes and standards implementation, and processes like those provided by the Institute of Nuclear Power Operations [INPO (i.e., criterion and guideline development, training and accreditation, event analysis and information exchange, plant evaluations, and assistance in improving nuclear-power-plant performance)].
- Observation 5: Domestic manufacturing should be conducted by U.S. industry. There should be an initiative to identify manufacturers of (say) pressure vessels. The current manufacturing could be doubled through a qualified-producers list.
- Observation 6: Financial packages should be offered; they would make U.S. manufacturers more competitive and successful.

Kazimi noted that foreign countries are now funding students to take U.S. industrial positions to gain experience. Matzie suggested that such programs be coordinated and expanded.

Miller noted that the report proposes focusing on the fact that other countries should take into consideration what is already done on nonproliferation by different U.S. agencies. Matzie said that the purpose of this suggestion is to help direct foreign countries away from recycling spent fuel. Miller said that the focus should be to put U.S. technology in place abroad. Martin pointed out that there is overlap among DOE offices. The proposal here is to coordinate programs and to focus on promoting the once-through spent-fuel management policy.

Bunn believed that there should be a broader perspective for the Subcommittee that includes safety and security. Some big issues for R&D are the capturing of knowledge gained by China during their deployment of nuclear power plants. Russia has a significant interest in nuclear R&D, also. In working with other countries, NE should cooperate with Japan, South Korea, and others; that would be a way of learning about technologies that are not currently the focus of interest in the United States.

Connery pointed out that the interagency working group is working together well. It is to look at what would be specifically of interest to DOE. On the subject of new countries going nuclear, the United States is behind the curve. It should develop a training curriculum and present it in appropriate ways for other countries. Bringing foreign countries in to observe the Nuclear Regulatory Commission is good, but the U.S. does not currently have a nuclear safety program, and it should be able to offer that type of expertise to other countries.

Alfred Sattelberger was asked to present the report of the Fuel-Cycle Research and Development Subcommittee.

The most recent meeting of the Subcommittee was on May 1, 2014; it reviewed the FY14 budget, the Nuclear Fuel Cycle Evaluation and Screening Study, material protection accounting and control strategies, and accident-tolerant fuels.

The Accident-Tolerant Fuels (ATF) program is very well managed with an impressive array of industry organizations (GE, AREVA, and Westinghouse), national laboratories, and universities participating. There is also significant international interest with a lot of collaboration. Any reduction in resources (currently about $30 million) for this very ambitious program is likely to place the 2016 and 2022 milestones at risk. That said, ATF should prioritize activities and develop contingency plans in the event that resources are reduced. The current program's focus on fuel and cladding does not address other lower-cost reactor enhancements. The Subcommittee appreciates the program's addressing of the implications of severe accidents on other plant components by performing system-response analyses. Domestic irradiation capabilities must be maintained and, if possible expanded. The Subcommittee strongly supports the restart of the TREAT facility, with which NE is currently moving forward.

The mission of the Material Protection, Accounting, and Control Technologies Program is to develop innovative technologies and analysis tools to enable next-generation nuclear materials management for

existing and future U.S. nuclear fuel cycles to manage and minimize proliferation and terrorism risk. Funding for this program is modest: $5 million in FY14 and $5.3 million proposed in FY15. The nuclear decommissioning trusts fund the best projects from this limited budget; support also comes from NEUP. Because the NRC has the responsibility for verifying and maintaining control of nuclear materials within the civilian nuclear fuel cycle, the program should increase interactions with the NRC in the area of fuel-storage consequence analysis. Some interactions are currently occurring. Some of the program's projects have near-term milestones, but the majority appear to be in the category of open-ended research with no discernible endpoints. The Subcommittee deems it advisable to do some long-term planning to develop direct objectives across the various research areas.

Presentations were provided to the Subcommittee on the Fuel-Cycle Options Study; and the Evaluation and Screening Study was chartered in late 2011. A copy of the main draft report was made available near the end of the May 1 meeting; the planned release is pending NNSA concurrence. Much of the detail underlying the evaluation of alternative fuel cycles is contained in appendices to the main report, which was not available to the Subcommittee at the time of the meeting. The study was intended to establish an appropriate set of criteria for comparative evaluation of fuel-cycle options as alternatives to the current once-through fuel cycle and to examine the impact of weighting factors on outcomes. The study appears to provide a comprehensive methodology for evaluating alternative fuel cycles and should be a valuable tool for international decision making. The study included a companion independent review team chaired by Michael Corradini and composed of individuals with diverse backgrounds and views. About 15 meetings of the review team were held between July 2012 and January 2014.

The review study used a logical framework and process to screen and evaluate alternative fuel cycles that may provide significant improvements over the current fuel cycle. The study used nine evaluation criteria (specified by DOE) to evaluate fully fuel-cycle alternatives. Altogether, 4398 fuel-cycle options were considered. Six benefit criteria and three challenge criteria were also set. An evaluation and screening software tool was developed by the team but has not been presented to the Subcommittee. A key result of the study is the characterization of four groups as the most promising fuel-cycle alternatives. All involve recycle; none require uranium enrichment; none are ready to be deployed; additional R&D is required to develop the appropriate technologies.

The study offered a couple of observations: Although the stated goal of the study is to inform DOE on R&D needs that would support the development of the most promising fuel-cycle options, the degree to which this evaluation drives decisions was not part of the charter nor was it discussed. In light of the potential for the study results to affect future R&D directions and funding allocations, it is critical for the community to have confidence in the results. Dissemination of the software tool will facilitate the evaluation.

The Subcommittee awaits a full presentation on the study, its methods, and its tools.

Ion asked if Corradini were the head of the team. Corradini answered that he was just a reviewer. He was impressed with the tool and its associated database. Herczeg noted that NEAC will be reviewing the report before it is released. He understood that the fuel-cycle catalog that was compiled is being used in a number of universities. Corradini said that there is an ability to update the tool's database, but there needs to be a process to approve updates before they are incorporated.

Bunn said that he would like to see the full report before voting on whether to accept it. There are questions about how seriously uncertainty was taken into consideration. Error bars are needed. He was made nervous given the experience with the closed fuel cycle, where greater costs, more safety challenges, and more technical challenges kept coming up. Corradini said that all of these questions had been raised by the integrated research projects and are discussed in Appendix F because the Subcommittee was asking similar questions.

Kazimi said that he did not understand the time span involved in the R&D that was recommended. Wigeland responded that the report has a long discussion of the implications of transitioning to a new fuel cycle and the time span over which the R&D needs to occur, as will be seen when the report is released. There is not a wide range in the time span of the R&D, but the range of facilities represents a wide range of performance, which constitutes a challenge.

Meserve asked about the status of the NNSA review. Sattelberger replied that, in review, the NNSA pointed out some disagreements in the statements made in the report. Those disagreements are being resolved now; the report should be completed in about 30 days.

Paperiello asked whether the report was talking about protecting spent fuels, new fuels, or what. Herczeg replied that the Subcommittee was looking at all the risks that could be encountered.

Mujid Kazimi was asked to present the report of the Nuclear Reactor Technology Subcommittee. The Subcommittee met on May 29 and 30. It heard reports that:

- INL conducted a tristructural-isotropic (TRISO) fuel test at 1800 °C for 300 hr with no release of fission gas. This test may open the design window of such fuel in high-temperature reactors.
- NE has initiated a program (with NRC agreement) to develop an approach to regulating non-water-cooled reactors. General design criteria will be developed for all concepts, and specific general design criteria will be developed for metal-cooled reactors and high-temperature gas reactors. Workshops are being held with invitees from all interested parties.
- The Next-Generation Nuclear Plant Program has been merged with the Advanced Reactors Program, with the technical coordinators of the former two activities assuming combined leadership.
- A review has been initiated of a new round of advanced reactor development proposals by industry. It will lead to the selection of some designs for funding by DOE.

The Subcommittee is pleased that DOE is undertaking a coordinated demonstration plan for an advanced power cycle. It avoids duplication, develops systems for a wider market, and has the potential for higher payoff for the dollars invested. The demonstration system has to be of sufficient size to incorporate the features of any eventual commercial units; 10 MWe appears to be a reasonable limit. It is appropriate to consider two demonstrations to bridge the current experience of 1 MWe to the commercial-unit size of about 100 MWe.

In the Nuclear Space and Defense Program, NE has provided radioisotope power systems that safely enabled deep space exploration for NASA as well as for national-security missions for five decades. The program also conducts analyses of designs of fission systems for power for and propulsion of space vehicles. NE's program is responsible for safety of the nuclear systems throughout the space missions. While NASA funded the hardware development for each mission, DOE funded the infrastructure that enabled the development and testing of new technology. The Subcommittee makes three observations about this program:

- In FY14, the funding for the infrastructure was transferred to NASA. This left little funding at DOE to directly manage the maintenance of the facilities and expertise. It is important for DOE and NASA to continue to work as partners in providing these power systems for specific missions within this new infrastructure arrangement. The Subcommittee would emphasize that, as the primary customer for these capabilities, NASA should continue to recognize the responsibilities associated with maintaining a strong infrastructure for this important activity.
- In 2007, NEAC expressed concern about the long-term supply of plutonium-238 for satisfying the needs of NASA for its deep-space missions. In a presentation to the Subcommittee, NE staff described how the DOE and NASA partnership has addressed this issue. There is now a funded program to produce plutonium-238 via neptunium irradiation in the ATR and High-Flux Isotope Reactor (HFIR) by 2020. Given the current inventory of plutonium-238, the planned rate of production should be sufficient to satisfy NASA mission needs.
- The fission power systems effort is currently a small part of NE's activities but is attracting increased attention. The NE staff expressed concern that NASA is not fully utilizing DOE's expertise and national laboratories. NASA seems to be developing a separate expertise within its organization and at NASA centers and NNSA laboratories. The Subcommittee recommends that the NE staff seek to reestablish a DOE–NASA partnership in this area and to develop a memorandum of understanding (MOU) to clearly delineate the scope and task details for the fission-power-system efforts. This MOU would emphasize the importance of DOE's role in

integration of the components to ensure a safe and reliable operation of the system, which capability has been developed over years of experience. To ensure adequate safety margins, DOE must retain this responsibility during development of any new fission power system and its components and eventually its implementation for a particular mission. Otherwise, design modifications at a late stage may become necessary. The Subcommittee hopes that the MOU would be developed soon and would spell out the respective obligations.

Hintz asked who would be funding plutonium production and whether that material would be restricted to NASA's use? Kazimi replied that NE will be providing funding. Caponiti said that the DOE capabilities that are being set up would not be restricted to NASA's use, but NASA is funding these activities, so the materials would be designated for its use. If there were to be a request for additional production, a funding mechanism would have to be worked out. NE is not currently producing any material but is standing up the capability to produce those materials by 2020: fabricating targets, using the ATR and HFIR to irradiate targets, and processing irradiated targets to produce the plutonium-238. The environmental analysis is complete, and a follow-up report has been completed.

Meserve asked if there were a stopgap storehouse for plutonium-238. Caponiti answered that the United States has 100 years' worth of neptunium from which to make plutonium-238.

Eisenhower asked the Committee members to comment on the day's presentations.

Paperiello said that he came away from this meeting more optimistically than ever before. He had seen a lot of focusing and coordinating being accomplished among national laboratories, universities, and industries.

Hintz said that Lyons's comments on the support from the President and Secretary were very affirming. The gap between natural gas and nuclear has to be addressed to promote nuclear power's potential contribution to utilities' long-term bottom lines. The Republicans do not want to tax carbon, but there is nonpartisan support for nuclear power and a desire to add diversity to the energy portfolio of the nation.

Christensen noted that the administration is supportive of nuclear power, and that the Secretary has publicly supported nuclear R&D. NE's budget is not under assault. This trend needs to be continued. In facilities, industry would like to get involved as would the university community. The most important topics to address need to be identified. High-performance computing will provide more bang for the buck in nuclear technology R&D through modeling and simulation.

Kazimi commented that integrated energy systems need to be pursued, and more should be said to this Committee about that topic. Reactor modeling should be expanded. The modeling effort should be more coordinated. He hoped to see more component integration for safety and reliability.

Matzie said that the analysis software needs to be rolled out to a broad range of users when it is ready and be *user-friendly*. Facts are lacking in the nuclear debate, and the externalities need to be quantified and appreciated. The fuel suppliers would use and support DOE user facilities.

Sattelberger pointed out that DOE user facilities are free if the results are publicly released. If a user wants to keep results private, the complete costs of the facility's use are due but are very reasonable. A domestically built demonstration fast reactor needs to be pursued.

Bunn noted that there is a tension between R&D and nuclear-policy issues on the international stage (commercial competition, safety, security, safeguards, etc.). The United States needs to work with other countries, and that effort is grossly underfunded. A full-time nuclear-safety coordinator is needed at the Department of State.

Juzaitis said that this fuel-cycle evaluation has made comparisons and rankings. However, he was worried about the use of the figure of merit and whether its use is appropriate here. In modeling and simulation, these presentations were outstanding; the complementarity of CASL and NEAMS is outstanding. CASL brings strength; NEAMS brings flexibility. He was worried about the funding; it needs to be increased. Increased simulation lowers R&D costs and time. Bunn responded that the figure of merit is a good way to look at a material as it is; it does not cover how easy the material can be made into bomb material.

Rempe said that the modeling and simulation program is stable; she hoped that it would continue to be so. She liked the bringing in of industry and universities to the facilities. Industry buy-in will depend on code validation.

Miller was proud of the direction and accomplishments of the previous 3.5 years. He had a hard time getting his arms around the international nuclear universe because it is so diverse and widespread. There are overlapping areas, and NE should be interacting with and integrating industry, the national laboratories, computational capabilities, etc.

Ion noted that the United States is blessed with large infrastructure and was pleased to note the awareness of the need for links. She was pleased to see the focus on facilities and their efficient use; the importance of highlighting critical facilities; and the benefits accruing from linking with other technologies in the energy landscape. She was pleased with the recognition of the importance of staying abreast with other nations' fuel-cycle developments through real projects and, by so doing, seeking to influence those developments.

Corradini commented that the Committee needs a subcommittee for angular cross-cutting, identifying where R&D would be most effective.

Meserve credited Lyons and his colleagues for their presentations. The silos that stifled programs in the past are being cross-cut. This Committee has an advisory role to NE, but there are issues that go beyond DOE. Concerns about those issues should be passed on to those who deal with those topics. At the previous meeting of this Committee, the Secretary was gloomy about the future of nuclear energy in the United States because of the lack of tools. Changes in that situation are being seen now. There is a growing understanding of the role of nuclear power in the mix of fuels. The attitudes have changed.

Eisenhower thanked the presenters. She stated that there were several stories to tell from this upbeat meeting: In Washington, some advances are seen; the national economy is still tough. The externalities of all types of power generation need to be thought about. There are facts needed to support decisions that have long-term effects. This Committee should double down on the recommendations of the Blue Ribbon Commission on America's Nuclear Future. The evidence presented about stovepipes' being dismantled is thrilling and presents a story worth repeating. DOE should do everything it can to develop a diverse national energy portfolio.

Lyons was asked to respond to these comments.

- On the need for nuclear energy facilities and on externalities, the Secretary has set up a committee for the *Quadrennial Energy Review*, which committee is looking at clean-energy strategies across the country. More people have been speaking out on externalities; two NRC commissioners have spoken out on the topic.
- In April, at a conference entitled Climate Solutions: The Role of Nuclear Power, which was sponsored by the Center for Climate and Energy Solutions, Carol Browner said that she had been opposed to nuclear power in the past but has come to see that nuclear power is essential for the future.
- The Office has responded to the report on NEAMS that was presented by NEAC 2 years ago, and a lot of effort had been expended on making NEAMS robust and responsive.
- DOE maintains a large performance database that can be used for validation and verification; an expert from Oak Ridge is looking at how that database can be exploited for those purposes on an international scale.
- The Office is interested in expanding high-performance computing use in universities.
- Industry is interested in allowing the use of its facilities for government and university R&D.
- The nation should be more proactive in advancing the once-through system in foreign countries. It should also maintain a knowledge of advances in closed cycles (1) to guide new nuclear countries that choose to go that way and (2) perhaps to adopt a closed cycle domestically in the future.
- DOE has been very active with Japan in standing up their version of INPO.
- A fuel-cycle options study could be looked at carefully.

- Space power is now funded by NASA, and the Office has close contacts with NASA.
- It also has active research activities with China (e.g., uranium extraction from seawater and molten-salt cooling systems).
- The Office strongly supports hybrid energy systems; there are several countries that that are anxious to work with the United States on that concept; a workshop is to be held on this topic in Idaho.
- When a code is put forth for international use, there are many considerations. Some control needs to be maintained over that code.
- On the international scene, NE does not have any activities in, say, 123 agreements; in cases like that, NEAC need not go into those topics.

The floor was opened to public comment. There being none, the meeting was adjourned at 3:56 p.m.

Respectfully submitted,
Frederick M. O'Hara, Jr.
Recording Secretary
June 19, 2014