Merits and Viability of Different Nuclear Fuel Cycles and Technology Options and the Waste Aspects of Advanced Nuclear Reactors

December 7-8, 2020
Virtual Meeting

PUBLIC AGENDA
Draft: December 2, 2020

Day 1: Monday, December 7, 2020 (All times are ET.)

PUBLIC SESSION 1

WEBEX connection details for December 7th:

Link:
https://nas-sec.webex.com/nas-sec/j.php?MTID=m73471161b56bc59af6621d9f658822d4

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12:00 pm – 12:05 pm **Call Open PUBLIC SESSION 1 to Order and Welcome**
Janice Dunn Lee, Committee Chair, and Charles Ferguson, Study Director

Theme: Versatile Test Reactor Project as Presented by Argonne National Laboratory and Idaho National Laboratory

12:05 pm – 12:25 pm	**Versatile Test Reactor (VTR) Project Status and Overview –** Mr. Thomas O'Connor, Director, Versatile Test Reactor Program, Office of Nuclear Energy, Department of Energy
12:25 pm – 12:40 pm	**Q&A for committee and presenters**
12:40 pm – 1:05 pm	**VTR Core Design and Fuel Selection –** Dr. Thomas Fanning, Manager, Safety and Engineering Analysis Department, Nuclear Science and Engineering Division, Argonne National Laboratory
1:05 pm – 1:25 pm	**Q&A for committee and presenters**
1:25 pm – 1:40 pm	**Brief Break**
1:40 pm – 2:00 pm	**VTR Experimental Capabilities –** Dr. Kevan Weaver, Director, Experimental Capabilities for the Versatile Test Reactor (VTR), Idaho National Laboratory
2:00 pm – 2:20 pm	**Q&A for committee and presenters**
2:20 pm – 2:45 pm	**VTR Fuel Cycle & Waste Management –** Dr. Douglas Crawford, Director of the Transient Reactor Test Facility (TREAT) at Idaho National Laboratory
2:45 pm – 3:05 pm	**Q&A for committee and presenters**
3:05 pm – 3:15 pm	**Public Comment Period**
3:15 pm	**Adjourn PUBLIC SESSION – Day 1**

Day 2: Tuesday, December 8, 2020 (All times are ET.)

PUBLIC SESSION 2

WEBEX connection details for December 8th:

Link:
https://nas-sec.webex.com/nas-sec/j.php?MTID=m915b61568b9a74b26ce164ce79da33bc
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12:00 pm – 12:05 pm	**Call Open PUBLIC SESSION 2 to Order and Welcome** Janice Dunn Lee, Committee Chair, and Charles Ferguson, Study Director **Theme: Perspectives from Argonne National Laboratory and Idaho National Laboratory on Advanced Fuel Cycles and Waste Management**
12:05 pm – 12:15 pm	**Systems Perspective on Advanced Fuel Cycles and Waste Management** – Dr. Temitope Taiwo, Interim Director, Nuclear Science and Engineering Division, Argonne National Laboratory
12:15 pm – 12:25 pm	**Q&A for committee and presenters**
12:25 pm – 12:35 pm	**Summary of DOE-NE Material Recovery & Waste Form Campaign R&D** – Dr. Terry Todd, Laboratory Fellow, Idaho National Laboratory
12:35 pm – 12:45 pm	**Q&A for committee and presenters**
12:45 pm – 1:10 pm	**Ceramic Fuel and TRISO Fuel Recycle Options** – Dr. Terry Todd
1:10 pm – 1:20 pm	**Q&A for committee and presenters**
1:20 pm – 1:40 pm	**Molten Salt Reactor Fuel Recycle Options** – Dr. Candido Pereira, Deputy Director, Chemical and Fuel Cycle Technologies Division, Argonne National Laboratory
1:40 pm – 1:55 pm	**Q&A for committee and presenters**
1:55 pm – 2:10 pm	**Brief Break**
2:10 pm – 2:30 pm	**Metal Fuel Recycle Options** – Dr. Mark Williamson, Division Director, Chemical and Fuel Cycle Technologies Division, Argonne National Laboratory
2:30 pm – 2:45 pm	**Q&A for committee and presenters**
2:45 pm – 3:05 pm	**Waste Form Development** – Dr. Bill Ebert, Manager, Pyroprocess and Waste Form Development, Chemical and Fuel Cycle Technologies Division, Argonne National Laboratory
3:05 pm – 3:20 pm	**Q&A for committee and presenters**

3:20 pm – 3:35 pm	**Nonproliferation Considerations** – Dr. Michael Miller, Director, Nuclear Nonproliferation, Idaho National Laboratory
3:35 pm – 3:50 pm	**Q&A for committee and presenters**
3:50 pm – 4:15 pm	**Economics of Future Fuel Cycle Options** – Mr. Brent Dixon, Deputy National Technical Director, DOE NE Systems Analysis & Integration, R&D Campaign, Idaho National Laboratory
4:15 pm – 4:30 pm	**Q&A for committee and presenters**
4:30 pm	**Adjourn PUBLIC SESSION – Day 2**

Presenter Biographies

Dr. Douglas C. Crawford, Director of the Transient Reactor Test Facility (TREAT) at Idaho National Laboratory

Dr. Doug Crawford is currently Director of the Transient Reactor Test Facility (TREAT) at Idaho National Laboratory (INL), responsible for staffing, strategic planning, and overall execution. He is also leading Fuel Design and Analysis for the Versatile Test Reactor (VTR). Crawford rejoined INL in July 2017 as Chief Scientist for the Materials & Fuels Complex, following his time at Oak Ridge National Laboratory where he served as reactor technology leader and GAIN deputy director. From 1990 to 2007 Crawford worked at Argonne National Laboratory-West and the INL. In 2007 he joined GE Hitachi Nuclear Energy in Wilmington, NC, where led engineering teams supporting boiling water reactor customers with fuel technology, reactor systems and components engineering, and reactor plant mechanical analysis. Crawford's subject matter expertise includes fast reactor and boiling water reactor fuel performance and design, fuel safety testing and licensing, fuel specification, technical leadership and issue resolution, and nuclear materials storage technology. He has earned B.S. Metallurgical Engineering, University of Idaho; M.S. Nuclear Engineering, University of Washington; Ph.D. Nuclear Engineering, University of Michigan; and MBA, University of Chicago.

Mr. Brent Dixon, Deputy National Technical Director, DOE NE Systems Analysis & Integration, R&D Campaign, Idaho National Laboratory

Mr. Dixon is the Deputy National Technical Director and multi-lab economics lead for Systems Analysis and Integration within the Office of Nuclear Energy and brings a specific perspective on nuclear technology and modeling of electricity generation and energy markets to the team. He contributes to metrics and scenario development and is a source of information for nuclear generation costs and performance. He is a U.S. representative to NEA and IAEA projects on scenario analysis and economics, including Vice Chair of NEA Working Party on Nuclear

Economics, Chair of NEA Expert Group on Advanced Fuel Cycle Scenarios, Joint IEA/NEA committee on the projected cost of electricity generation, and IAEA INPRO nuclear futures and technology roadmapping. He participates in various engineering analysis and tools development work for DOE-NE, DOE-EM and DoD (Army) in applied mechanics, artificial intelligence, probabilistic risk assessment, strategic planning, technology roadmapping, multi-attribute decision assessment, systems analysis, and software systems development. This background has provided experience in assessment of defense in depth systems, the evolution of systems as technologies evolve, how to assess balancing of multiple conflicting objectives in system design, and an understanding of how software architectures and algorithms selection in tools development implicitly impact analysis results.

Dr. William Ebert, Manager, Pyroprocess and Waste Form Development, Chemical and Fuel Cycle Technologies Division, Argonne National Laboratory

Dr. Ebert manages the Pyroprocess and Waste Form Development Group in the Chemical and Fuel Cycle Technologies (CFCT) Division at Argonne National Laboratory and oversees a range of projects addressing various molten salt-based technologies, including pyroprocessing and salt property measurements, material corrosion in molten salt and aqueous systems, and nuclear waste form development. He received his PhD in chemistry from Northwestern University and has more than 30 years of experience leading projects sponsored by various DOE offices supporting various nuclear related programs and collaborations with national laboratories and universities. He has served on several ad hoc review committees as a waste form expert. He is currently leading or participating in multi-laboratory research collaborations to develop advanced waste forms for reprocessing waste and mechanistically-based degradation models for engineered waste forms and directly disposed spent fuel that are being used for repository design and qualification. Dr. Ebert is active in developing standardized materials test methods through the ASTM-International Nuclear Fuel Cycle committee and American Nuclear Society Environmental and Siting Consensus committee.

Dr. Thomas H. Fanning, Manager, Safety and Engineering Analysis Department, Nuclear Science and Engineering Division, Argonne National Laboratory

Dr. Fanning received his Ph.D. in Nuclear Engineering and Engineering Physics from the University of Wisconsin and has worked at Argonne National Laboratory since 1994. He has made significant contributions in the areas of core design, fuel cycle analysis, waste form development, repository modeling, advanced systems modeling, and reactor safety. His primary research focus is on the development of codes and methods for fast reactor safety analysis. He currently manages the Safety and Engineering Analysis Group and oversees methods development and applications for a wide range of advanced reactor systems analysis activities. Dr. Fanning is the code manager for the SAS4A/SASSYS-1 safety analysis system and has extensive expertise in fast reactor design and safety. He was a member of the American Nuclear Society Special Committee on SMR Generic Licensing Issues and was nominated for the National Academy of Engineering's 2010 Frontiers of Engineering. From 2014 to 2017 Dr. Fanning served as the U.S. representative for the Generation IV International Forum Sodium Fast Reactor Safety and Operations Project Management Board. He currently serves as the U.S. representative for the Generation IV Expert Group and is the Nuclear Design Technical Integration Lead for the Versatile Test Reactor Project.

Dr. Michael Miller, Director, Nuclear Nonproliferation, Idaho National Laboratory

Dr. Michael Miller is the Director of Nuclear Nonproliferation at the Idaho National Laboratory (INL). Prior to joining INL, Mike spent over 30 years in national security, nonproliferation, and civilian nuclear energy R&D programs at Los Alamos National Laboratory, Lawrence Livermore National Laboratory and the Defense Threat Reduction Agency. Mike has held a variety of leadership positions, including National Chair of the NIF Radiation Science Users Group at LLNL, Group Leader of the Safeguards Science and Technology group and Civilian Nuclear Energy Programs Manager at LANL. He has more than 100 publications involving x-ray, gamma-ray, and neutron instrumentation used in process monitoring, waste management, domestic and international safeguards, planetary exploration, and diagnosing high-temperature plasmas.

Mr. Thomas J. O'Connor, Director, Versatile Test Reactor Program, Office of Nuclear Energy, Department of Energy

Thomas J. O'Connor is the Director of the Versatile Test Reactor Program with overall responsibility for design, cost and schedule, fuel supply, environmental compliance, budget development and interface with senior government officials, industry and university stakeholders. Mr. O'Connor's 37 years of management and operational experience in all aspects of nuclear science and technology includes management of Department of Energy advanced reactor R&D programs, radioisotope production infrastructure, nuclear facility construction and operations, and safety management oversight. Mr. O'Connor's experience extends to the commercial nuclear power sector, including construction with Stone & Webster Engineering Corporation, regulatory oversight with the Nuclear Regulatory Commission, and utility experience with the former Virginia Power. International experience includes having served as the US Representative to the Generation IV International Forum Policy Group, a nuclear R&D partnership of 12 countries and the European Union, dedicated to collaborating on the next generation of nuclear reactors. Mr. O'Connor received a Bachelor of Science degree in Mechanical Engineering from the University of Notre Dame and a Master of Science in Mechanical Engineering from the Georgia Institute of Technology.

Dr. Kemal Pasamehmetoglu, Executive Director for the Versatile Test Reactor (VTR) Project, Idaho National Laboratory

Dr. Kemal Pasamehmetoglu has been with the Idaho National Laboratory (INL) since 2004, currently serving as the Executive Director for the Versatile Test Reactor (VTR) Project. Previously he served as the Associate Laboratory Director for the Nuclear Science & Technology Directorate between 2012 and 2017. He was instrumental in the launch of the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative and initially served as the director for GAIN after its inception. Kemal also served as the national technical director (NTD) for Advanced Fuels Research and Development in the Advanced Fuel Cycle Initiative while also serving as the Nuclear Fuels and Materials Division Director at INL between 2005 and 2012. During his tenure as a fuels and materials division director and as a NTD he has focused on transforming nuclear fuels research and development capabilities in the nation and at INL into world-leading endeavors. Prior to his time at INL, he held senior technical leadership positions at Los Alamos National Laboratory where he worked between 1986 and 2004. He started his career working on light-water reactor safety research. He holds a doctorate in mechanical engineering from the University of Central Florida and has more than

34 years of research and engineering experience within the Department of Energy (DOE) National Laboratory system.

Dr. Candido Pereira, Deputy Director, Chemical and Fuel Cycle Technologies Division, Argonne National Laboratory

Dr. Pereira is Deputy Director of the Chemical and Fuel Cycle Technologies Division at Argonne National Laboratory. During his time at Argonne, Dr. Pereira has worked on a number of projects related to the treatment of spent nuclear fuel by solvent extraction and pyroprocessing. His recent research has focused on the application of advanced simulations to process, facility, and safeguards design. These efforts include developing codes for designing solvent extraction flowsheets and pyrochemical separations, as well as other key unit operations that constitute spent fuel treatment facilities. Much of this work is centered on development and testing of process equipment, and experimental chemical studies to support process implementation. Other areas of recent focus include novel sensors for rapid on-line analysis, additive manufacturing to prototype specialized equipment, and microfluidic techniques for rapid sampling and statistical analysis. He has a PhD in Chemical Engineering from the University of Pennsylvania.

Dr. Jordi Roglans-Ribas, Deputy Project Manager (currently Acting Project Manager) of the Versatile Test Reactor, Argonne National Laboratory

Jordi Roglans-Ribas is the Deputy Project Manager (currently Acting Project Manager) of the Versatile Test Reactor. He served as Director of Argonne's Nuclear Science and Engineering (previously Nuclear Engineering) Division from 2014 to 2019. He is a senior nuclear engineer and has been with Argonne since 1987. Previously, Dr. Roglans-Ribas was the Argonne Program Director for the National Nuclear Security Administration's Material Management and Minimization-Reactor Conversion program. Dr. Roglans-Ribas' previous assignments include Associate Director of Argonne's Advanced Fuel Cycle Initiative Program, Technical Director of the International Expert Group for the development of assessment methodologies for proliferation resistance and physical protection of Generation IV nuclear energy systems, co-chair of the Evaluation Methodology Group during the Generation IV nuclear energy systems Technology Roadmap, and US system integration manager and co-chair of the Generation IV International Forum Steering Committee for the Sodium-Cooled Fast Reactor (SFR). Dr. Roglans-Ribas also worked as project manager in the Plant Safety Evaluation element of the US Department of Energy's International Nuclear Safety Program, leading projects in safety analyses and computational tool validation for Russian- designed nuclear power plants, as well as analysis of SFRs and associated facilities. He earned his PhD in Nuclear Engineering from Iowa State University and his Engineering degree from the Polytechnic University of Catalonia.

Dr. Temitope Taiwo, Interim Director, Nuclear Science and Engineering Division, Argonne National Laboratory

Dr. Temitope Taiwo is the Interim Director of Argonne's Nuclear Science and Engineering Division. He has worked in the nuclear industry, research laboratory, and U.S. government in the areas of reactor design, methods development, and analysis. He has been at Argonne since

1990 and in that time has led research teams and developed computational tools and methods and performed analysis of nuclear energy systems, including fast and thermal reactors. During 1995 to 1996, he performed assessments of international nuclear security and non-proliferation issues for the U.S. Government. Prior to employment at Argonne, he worked as a nuclear reactor analyst at the Northeast Utilities in Connecticut, where he was part of the code development and reactor analysis team. He developed nuclear analysis computer models and methods in support of Light-Water-Reactor core reloads, and designed and analyzed reload cycles. Dr. Taiwo is currently the National Technical Director of the Systems Analysis and Integration Campaign of the DOE Nuclear Fuel Cycle and Supply Chain office. He was previously a co-Dean of the Modeling, Experimentation and Validation (MeV) Summer School. He is a Fellow of the American Nuclear Society. He has a Ph.D. in Nuclear Engineering, from the Massachusetts Institute of Technology, and a B.Sc. in Engineering Physics (Nuclear Option) from the University of Ife, Nigeria.

Dr. Terry Todd, Laboratory Fellow, Idaho National Laboratory

Dr. Terry Todd is a Laboratory Fellow and former Director of the Fuel Cycle Science and Technology Division at Idaho National Laboratory. His primary focus is directing research and development of advanced technologies for spent nuclear fuel recycle and other chemical separation applications. He also serves as the National Technical Director for the DOE Nuclear Technology Research and Development Material Recovery and Waste Form Development Program. He is also the inaugural and current Director of the Glenn T. Seaborg Institute at the INL, which was formed in 2017. Terry has 40 years of experience in chemical separation technologies involving spent nuclear fuel and radioactive waste. He holds B.S. and M.S. degrees in chemical engineering from Montana State University and a Ph.D. in chemical engineering from Khlopin Radium Institute in St. Petersburg, Russia. He is a fellow of the American Nuclear Society and the American Institute of Chemical Engineers. He has published over 250 journal articles, reports and conference proceedings and has been awarded 23 US patents and 6 Russian patents. He has received several national awards including: the Glenn T. Seaborg Actinide Separations Award (2005), R&D 100 award (2006), AIChE Nuclear Engineering Division Robert E. Wilson Award (2011) and the Secretary of Energy's Achievement Award (2013). He serves on the Editorial Board for the journal Solvent Extraction and Ion Exchange.

Dr. Kevan Weaver, Director, Experimental Capabilities for the Versatile Test Reactor (VTR), Idaho National Laboratory

Dr. Kevan Weaver re-joined the Idaho National Laboratory (INL) in the spring of 2018 and is currently the director of experimental capabilities for the Versatile Test Reactor (VTR), a proposed fast spectrum test reactor to be designed and built for the US Department of Energy. In this capacity, Dr. Weaver leads a team composed of 6 national laboratories, 19 university partners, and 8 industry partners in the development of advanced experiment vehicles and experiment infrastructure for the VTR. He is also the technical lead for reactor systems safety, where he leads the effort on integrated transient testing of advanced reactor fuels, and is a lead for the development of a micro-reactor concepts with industry partners. Previous to re-joining

INL, Dr. Weaver worked at TerraPower from 2007 until 2018, holding various positions including technical fellow, director of technology integration, and director of technology development, among others. In these capacities he was responsible for identifying, developing and maintaining U.S. and international joint programs and relationships that supported TerraPower technology development for their various fast reactor programs. Before joining TerraPower, Dr. Weaver worked at INL for more than nine years (1998-2007) in various capacities, all related to the development and use of advanced nuclear reactor concepts. With much of his career in advanced reactor design and analysis, Dr. Weaver initiated and executed complex test programs for advanced fast reactor concepts, and collaborated with fellow researchers on Generation IV nuclear energy systems, the Generation IV International Forum, and the Advanced Fuel Cycle Initiative. His experience has allowed him to focus on some of the critical technical challenges facing advanced reactor concepts, such as the development and testing of advanced nuclear fuels and materials. His technical background includes reactor physics, reactor design, fuel cycle analysis, radiation spectroscopy, radioisotope production, and reactor operations. In addition, Dr. Weaver is the author/co-author of more than 90 publications and technical reports in nuclear science and engineering, and is a co-author of a textbook on fast spectrum reactors. Dr. Weaver holds a BS degree in physics, and PhD degree in nuclear engineering.

Dr. Mark Williamson, Division Director, Chemical and Fuel Cycle Technologies Division, Argonne National Laboratory

Dr. Mark A. Williamson is the Division Director of the Chemical and Fuel Cycle Technologies Division at Argonne National Laboratory. He leads Argonne's nuclear chemical engineering team with research and development activities in used nuclear fuel recycling, fuel fabrication and safeguards for next-generation nuclear energy systems, and radioisotope generation and separation systems for future application in the medical and industrial sectors. His technical career has focused on developing pyrochemical processing technologies for sustainable nuclear energy systems. He has extensive experience in molten salt chemistry and property measurement; chemical process design, development, and demonstration; equipment engineering; and facility design. His work includes the transformation of unit operations from concept to pilot scale with a focus toward technology commercialization. He received his Ph.D. in chemistry from the University of Kansas, and degrees in chemistry and mathematics from the University of Toledo.

Advance Questions from the Committee

Theme: Versatile Test Reactor Project as Presented by Argonne National Laboratory and Idaho National Laboratory

- Is the mission need only as a dedicated fast neutron test reactor (replacing the FFTF to fill a long-standing gap in nuclear research infrastructure) or is it also needed to support fast reactor development?

- How will the VTR be different in terms of economics and safety/reliability from the previous Na-cooled fast reactors like the EBR-II and the FFTF?
- Could the Work Breakdown Structure, cost, and schedule information be made available to the committee?
- Concerning the Environmental Impact Statement status, are there any major obstacles which would significantly slow down or stop the project?
- Please provide a listing of partners and a reasonable description of the responsibilities of each. Do any of the partners have deliverables that are on a critical path to project completion? Which ones and what deliverables?
- Please discuss the anticipated government/private testing ratio and any identified/anticipated customers. Will the project be open to all international customers, both government and private?
- Are there any primary government customers who may dictate overall core/loop characteristics impacting overall test capabilities?
- What is the process of working with potential customers to develop overall test capabilities?
- Please provide a conceptual discussion of the commercial model.
- Concerning the design approach when specific decisions were made, could the reasoning behind those decisions be provided?
- Please discuss all expected radioactive waste streams including VLLW, LLW, ILW, and HLW, off-gas, effluent, etc. from normal reactor operations. What are estimated typical volumes and physical, chemical, and isotopic characteristics (moles/MWd/MTHM) of the waste streams from one cycle of discharged fuel (at design basis level of burnup) for the baseline reactor design?
- How will they manage these wastes (cooling pools, dry storage, reprocessing, etc.)? How have then folded in the costs of waste management (including reprocessing) into their economic forecasts? How have they considered transportation and the ability to store used fuel and associated wastes under the current regulations?
- Can they give the committee a sense of costs for the whole project overall?
- Is eventual pyroprocessing of Na-based spent fuel anticipated? Could they provide a status of the EBR II pyroprocessing campaign?
- Is there any analysis or R&D on safeguards for the VTR Project?
- For experimental capabilities, what is meant by a vehicle?
- How many “in core” test loops are anticipated?

- Please provide a conceptual discussion of any additional test ports.
- Please provide a conceptual discussion of test trains and test train handling and examination facility as well as online insertion capability (for one or more loops), if planned.
- Please discuss conceptually any test loops planned with independent advanced coolant capability (such as in - loop liquid metal) and/or independent temperature/ pressure capability.
- Are there anticipated reactor test cycles and open or closed core test insertion/removal capability?

Theme: Perspectives from Argonne National Laboratory and Idaho National Laboratory on Advanced Fuel Cycles and Waste Management

- What is their plan for qualifying their advanced waste forms?
- Please discuss all expected radioactive waste streams including VLLW, LLW, ILW, and HLW, off-gas, effluent, etc. from normal reactor operations. What are estimated typical volumes and physical, chemical, and isotopic characteristics (moles/MWd/MTHM) of the waste streams from one cycle of discharged fuel (at design basis level of burnup) for the baseline reactor design?
- How does the radionuclide inventory generated by each reactor type/fuel cycle vary over time?
- How will they manage these wastes (cooling pools, dry storage, reprocessing, etc.)? How have then folded in the costs of waste management (including reprocessing) into their economic forecasts? How have they considered transportation and the ability to store used fuel and associated wastes under the current regulations?
- Which reactor types do your recycling technologies support?
- Is eventual pyroprocessing of Na-based spent fuel anticipated? Could they provide a status of the EBR II pyroprocessing campaign?
- What are the most challenging technical issues that must be overcome for commercialization of your baseline recycling technologies?

Please discuss nonproliferation and safeguards approaches for each fuel cycle being investigated.