ANS WINTER MEETING

Joining forces to advance nuclear

Session Coverage:

- *The importance of partnerships between industry, government, academia, and NGOs*
- *Progress in policy, outreach and advocacy, and the UAE's nuclear power program*
- *Innovations in the development of microreactors*
- *Grand Challenge: Closing the nuclear fuel cycle*
- *Continuing challenges for waste management*

A report on the opening plenary session of the ANS Topical Meeting on Advances in Thermal Hydraulics, held in conjunction with the 2018 Winter Meeting, will appear in the February issue of *Nuclear News*.

The importance of collaboration among the various segments of the nuclear community was the major message at the 2018 ANS Winter Meeting, held November 11–15 in Orlando, Fla., including at the opening plenary session. In his introductory remarks, ANS President John Kelly said, "That is what ANS is all about—providing a way for us all to join forces to talk about solutions for nuclear waste and efforts to close the fuel cycle, maintain America's leadership in nuclear energy by keeping our plants operating, and advocate for future research and development and next-generation reactors. By banding together for all the applications for nuclear technology, we can make a difference."

Photo: Greg Cohen/ProView Events LLC

Kelly

Before introducing the plenary session speakers, Daniel Churchman, fleet engineering director at Southern Nuclear, who served as general chair of the meeting, noted the U.S. power sector's current focus on carbon emissions reduction, energy independence, and national security and called on government, academia, and industry to unite. "If we join together, make sure we're aligned on the initiatives and what we can do to help each other, then we have an opportunity to really take advantage of the situation right now," he said.

Photo: Greg Cohen/ProView Events LLC

Churchman

The first speaker was Tom Bergman, vice president of regulatory affairs at NuScale Power, developer of the NuScale small modular reactor. Bergman noted that since 2012, NuScale has engaged in more than 70 research collaborations with external organizations, including 17 industry partners, 17 universities (among them Kansas State University, Texas A&M University, the University of Florida, the University of Idaho, and the University of Tennessee), and eight Department of Energy national laboratories. These collaborations, he said, are vital in order to gain access to additional funding streams, expertise, and special facilities, as well as to build a future staffing pipeline.

Bergman said that while NuScale has to date spent some $80 million of its own funds on the development of its SMR, the company has been able to leverage that amount to well over $100 million, primarily via DOE-sponsored university and laboratory grants. "If you're a small company, you simply cannot afford to develop all the specific expertise you need and all the facilities you need to demonstrate the safety of your design, so you have to collaborate with others," he said. "And we're a light-water reactor, so you have to think about the implications for a different design and how much more important collaboration will be to those developers."

Photo: Greg Cohen/ProView Events LLC

Bergman

NuScale has partnered with academic institutions on a number of research projects, Bergman said, including one with the United Kingdom's University of Sheffield that assessed the reliability of the company's "redundant array of independent reactors" to supply power to mission-critical facilities, such as military bases, hospitals, and data storage centers, and one (ongoing at this writing) with Brookhaven National Laboratory to develop a methodology to quantitatively assess the consequences of cyberattacks on the safety, reliability, and availability of nuclear power plants.

In addition, Bergman said, NuScale has teamed up with a variety of organizations for "diverse energy platform studies." One of these studies, conducted in collaboration with Fluor, looked at a typical quarter-million-barrel-per-day oil refinery. "A 10-module [NuScale plant] provides the process heat necessary to avoid 190 metric tons per hour of CO_2 emissions," he said. "It may sound odd. You

have an oil refinery—you obviously have plenty of energy there—so why would you want to use a nuclear plant to provide heat? But the oil is actually more valuable sold than burned."

Bergman also acknowledged the assistance that NuScale receives from the industry through its advisory board, which is currently composed of representatives from 29 companies, including owners and operators of nearly two-thirds of the U.S. operating fleet of commercial nuclear power plants. The board, which meets twice a year, offers advice and input on design, operation, maintenance, and regulatory strategies. NuScale also has a technical advisory board made up of former NRC commissioners and individuals from the industry that provides more detailed input on technical and regulatory matters.

"The point is, to succeed in this industry, to keep moving forward, you can't do it alone," Bergman said. "You'll just never pull it off the first time by yourself, especially if you're a small company. Bringing in partners from government, academia, and industry is the real path to success for new innovative technology."

Speaking next was David Hill, chief technical officer at Terrestrial Energy, developer of the Integral Molten Salt Reactor, the conceptual design phase for which was completed in mid-2016. Hill provided an overview of the technology behind the IMSR, as well as a look at the company's efforts to achieve IMSR commercialization in the United States before 2030 through collaborations. "We're a small company, and we cooperate with everybody we can possibly cooperate with to deliver the technology," he said. "The world is littered with paper reactors. The trick is, can you get it through the regulatory process? Can you support your technology decisions? . . . Design acceptance, which is our goal, has to be accelerated by focused cooperation with labs and universities, U.S. and worldwide—and the key word here is 'focused.' We support and encourage work that really helps address immediate questions on the path to commercialization."

Photo: Greg Cohen/ProView Events LLC

Hill

According to Hill, the federal government can support nuclear innovation at companies like Terrestrial Energy by reducing various kinds of risk. Financial risk, he said, could be reduced by continuing the DOE's loan guarantee program, long-term federal power purchase agreements, and funding of the Nuclear Regulatory Commission's licensing activities. Technical risks could also be reduced, Hill said, by continuing support through the Industry Funding Opportunity Announcement, the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative, and national laboratory and university programs. "We have GAIN projects with Argonne and are in the process of putting together one with Oak Ridge," he said.

Regulatory risks could be lessened as well, Hill noted, by continuing the "transformational" progress at the NRC, including progress on developing the licensing framework for advanced reactors. In addition, policy risks, in Hill's view, could be decreased by recognizing small-business realities and associated limitations. "We don't have a staff lawyer," he said. "So when we negotiate with the DOE or anybody else on contracts, we have to purchase services. It turns out that a long, complicated negotiation costs us so much money that the project may not be worth it in the end. The government systems—and it is not vindictive on their part, it is just the way they've grown—are geared to working with large companies."

Other ways to reduce policy risks, Hill continued, include encouraging active public-private partnerships and ensuring meaningful public recognition of all reactor technologies. "When you go out and ask somebody to give you a very large amount of money to support an activity," he said, "they will usually do their due diligence and find out more about it. Well, some of the places they will go, not surprisingly, are to government websites. . . . If the picture they get when they look there is dominated by some technologies over others, they will conclude, correctly or not, that the U.S. government favors these technologies. So it is very important in this rapidly evolving private marketplace, where capital is being raised to support these activities, that the public-facing websites are even-handed. It may sound like a small thing, but it is actually very important in capital markets."

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Following Hill was Per Peterson, chief nuclear officer of Kairos Power and a professor of nuclear engineering at the University of California at Berkeley, who provided an overview of his company's advanced reactor work and collaborative activities. According to Peterson, the principal goal of Kairos Power is to commercialize fluoride salt–cooled high-temperature reactor (FHR) technology, and, like Terrestrial Energy, to do so before 2030.

The key elements of FHR development, Peterson said, "include the use of a unique high-temperature yet low-pressure primary heat supply system, the extensive use of rapid iteration and testing—something that SpaceX was able to implement in their rocket development and which we are also using in the development of Kairos technology—and then finally, the licensing strategy around this technology, which is designed to leverage intrinsic safety characteristics. We spend quite a bit of time looking at the licensing dimensions and are already actively engaged in pre-application review with the NRC."

Photo: Greg Cohen/ProView Events LLC

Peterson

Peterson emphasized "the extraordinarily important role" that the DOE, international partners, and universities have played in building a foundation on which ambitious startup companies, such as Kairos Power, can be launched. The company's FHR technology, he noted, is built on major DOE investments in national laboratory and university R&D. These investments include multiple conceptual design studies at UC Berkeley and Oak Ridge National Laboratory, which provided a basis for being able to study and develop the technology, "as well as a strong experimental basis, including methodologies for performing scaled experiments at lower temperatures, where you can more easily extract high-quality data to validate models." The DOE also provided $20.5 million for three FHR Integrated Research Projects involving the Georgia Institute of Technology, the Massachusetts Institute of Technology, Ohio State University, Texas A&M University, UC Berkeley, the University of Michigan, the University of New Mexico, and the University of Wisconsin.

"It is impossible for us to have a functional nuclear industry without a robust government role, particularly in terms of support for national laboratories and for that basic infrastructure of research reactors, hot cells, and other capabilities that private industry cannot and should not be expected to maintain," Peterson said. "And building on that infrastructure is extraordinarily important for us. The oth-

er thing the federal government needs to do is to fix major policy flaws. . . . What we need are technology-neutral clean-energy standards. If we have a level playing field, we'll be able to compete perfectly well."

Enabling the world's transition to clean energy will also require efforts by the nuclear industry and nongovernmental organizations (NGO), Peterson added. The industry needs to commit to delivering the products that customers need, when they need them, and to reinvent and modernize the nuclear supply chain, he said, while NGOs should continue to challenge the old, incumbent environmental organizations to focus on realistic strategies and policies to enable the transition. Peterson specifically mentioned work by the Clean Air Task Force, Clear Path, Third Way, and the Nuclear Innovation Alliance.

"We are seeing that it is very important to engage the industry with the government to make sure that we can put together suitable public-private partnerships to deploy, in a cost-effective manner, new nuclear technologies."

The plenary session's final speaker, Sama Bilbao y Leon, head of the Division of Nuclear Technology Development and Economics at the OECD Nuclear Energy Agency, began by providing some background on the organization, which, she said, "is in a particularly good position to provide a bigger, global picture of how we can join forces to advance nuclear energy." She said that the NEA assists member countries in maintaining and further developing, through international cooperation, the scientific, technological, and legal bases required for the safe, environmentally sound, and economical use of nuclear energy. This is accomplished, she said, by providing "authoritative assessments" and forging "common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and the sustainable development of low-carbon economies."

Photo: Greg Cohen/ProView Events LLC

Bilbao y Leon

Bilbao y Leon referred to the NEA's standing technical committees, noting that they bring together top governmental officials and technical specialists from NEA member countries and strategic partners to solve difficult problems, establish best practices, and promote international collaboration. She said that the NEA has tried to increase the involvement of the nuclear industry, both vendors and utilities. "We are seeing, more and more, that it is very important to engage the industry with the government to make sure that we can put together suitable public-private partnerships to deploy, in a cost-effective manner, new nuclear technologies," she said.

The NEA works with a number of organizations to promote collaboration to advance nuclear, Bilbao y Leon said, including the Generation IV International Forum, a framework for international cooperation to improve sustainability, economics, safety and reliability, proliferation resistance, and physical protection of next-generation nuclear energy systems, and the International Framework for Nuclear Energy Cooperation, a forum for international discussion on a wide range of nuclear topics involving both developed and emerging economies.

In addition, the NEA is involved in a variety of joint projects, expert groups, and cross-cutting initiatives, Bilbao y Leon said, including Nuclear Innovation 2050, to enable accelerated and cost-effective market deployment of "disruptive ideas applied to the nuclear enterprise," and the Nuclear Education, Skills and Technology Framework, to help address important gaps in nuclear skills capacity building, knowledge transfer, and technical innovation in an international context and to energize advanced students to pursue careers in the nuclear field by proposing a multinational framework among interested countries to maintain and build skills capabilities; establishing international links between universities, academia, research institutes, and industry; and attracting technologists from other disciplines to examine nuclear technology issues and involving them in the resolution of real-world problems.

Bilbao y Leon observed that a shift in focus toward low-carbon electricity is occurring, including in the industrial and transportation sectors. "We are starting to see a little bit of a change in the narrative that many organizations and many governments are putting forward when they talk about energy," she said. "The new narrative is the decarbonization of electricity markets. All fuels and all technologies may be considered as suitable sources of energy as long as they are low carbon. . . . Yes, it is true that variable and renewable sources are expected to lead, but all the other energy sources are going to be needed, and I think we all agree in this room that nuclear power, as the only dispatchable low-carbon, large-scale energy source that we currently have, will also play a key role."

These new energy markets, Bilbao y Leon continued, are going to pose new challenges in the areas of technology, economics, and policy. "There will be a need for improved infrastructures to ensure interconnectivity, a need for energy sources to be much more flexible, and a need for a large level of coordination in policy and regulation," she said.

President's Special Session

ANS President John Kelly opened his President's Special Session, "Moving Forward on Nuclear," by noting the progress being made on many fronts regarding nuclear energy. With the long lead times associated with the technology—the research and development required to develop new reactor designs, licensing and construction timelines, even the time it takes to educate a new generation of nuclear scientists and professionals—it is easy to miss the rapid progress that is being made, he said.

Photo: Greg Cohen/ProView Events LLC

Kelly

Many firsts occurred in 2018, Kelly said, including new reactor designs entering commercial service, advanced reactor developers reaching new milestones, and new progress being made on nuclear policy and regulatory reform to keep operating reactors in service. First and foremost, he said, was the start of commercial operation of Generation III+ reactors—the AP1000 and the EPR—in China. Also, the first of four APR1400 reactors being built in the United Arab Emirates will soon be loaded with fuel for the first time. Kelly also mentioned the important milestones reached on small modular reactors, including the Nuclear Regulatory Commission's design certification work on NuScale's light-water-cooled SMR and the review by Canada's nuclear regulator of Terrestrial Energy's Integral Molten Salt Reactor design.

The session's first speaker was Michael Corradini, professor emeritus of engineering physics at the University of Wisconsin and an ANS past president (2012–2013). Corradini's presentation focused on a report, *The Future of Nuclear Energy in a Carbon-Constrained World*, based on a


Photo: Greg Cohen/ProView Events LLC
Corradini

study that he codirected and was conducted with a team from the Massachusetts Institute of Technology. The key finding of the report, he said, was that carbon emissions provide an opportunity for nuclear energy. However, for nuclear to be a contender, he said, costs must be reduced, and to accomplish that, government help is needed.

Corradini focused on the following key questions covered in the study:

- What is the role of nuclear in decarbonizing the power sector?
- What is the cost of nuclear and how can it be reduced?
- What is the appropriate role of the government in the development and demonstration of new nuclear technologies?

In answer to the first question, Corradini said that the report makes clear that excluding nuclear energy drives up the cost of electricity in low-carbon scenarios. The study looked at several regions—in the United States, China, and Europe—that demonstrated this conclusion. First, looking at situations with high carbon emissions and no requirements to constrain carbon releases, nuclear power really doesn't play a role. The study found, however, that if carbon constraints are progressively introduced to reduce the level of carbon emissions, the cost of power rises significantly if nuclear is excluded. This was seen in all of the regions included in the study.

Corradini also described the situation in terms of the levels of carbon emissions, from the business-as-usual scenario of 500 grams of carbon dioxide emitted per kilowatt-hour to the level called for under the 2015 Paris climate agreement of about 1 to 10 g of carbon dioxide emissions per kWh. In order for nuclear power to make a big contribution to that goal, the cost of new nuclear generation would need to drop, he said. According to Corradini, if the cost of new nuclear generation were to be decreased by only 25 percent, nuclear could make a large market penetration in terms of installed capacity, even at modest carbon constraints, ensuring a large reduction in emissions.

On the question of nuclear construction costs and how to reduce them, Corradini set out construction costs using historical data from the United States, France, India, and others, and recent cost data from South Korea, the UAE, China, the United States (for the AP1000), the United Kingdom (the UKEPR), and others. Construction costs differ, Corradini said, and lower costs result from an increased focus on using proven construction project management practices that increase the probability of success with the execution and delivery of new nuclear power plants at projected costs, including the following:

- Complete the plant design before starting construction.
- Develop a proven supply chain for the nuclear steam supply system and a skilled labor force.
- Include fabricators and constructors on the design team.
- Appoint a single primary contract manager.
- Adopt a contract administrative process that allows for adjustments to unanticipated changes.
- Operate in a flexible regulatory environment that can accommodate changes in design and construction in a timely manner.

Corradini noted the report's recommendations for reducing construction costs, with the biggest opportunity presented by shifting from field construction of site-dependent plants to serial manufacturing of standardized plants. This was true, he said, for all plant designs and all technologies, with standardization on multiunit sites showing particularly large benefits. He also acknowledged the importance of modular construction and the new technologies of seismic isolation and advanced concrete solutions, which are supported by the Department of Energy's Nuclear Engineering Enabling Technologies program.

Although Corradini has seen some improvement, he favors a more ambitious goal: to ensure technology neutrality in capacity markets, thereby avoiding a situation where the policies chosen will essentially determine the winners.

Regarding the appropriate role for government, Corradini focused on the need to preserve the existing fleet, which, he said, is an essential bridge to the future. Current plants are the lowest-cost way to constrain carbon emissions, and the report uses as an example the state of New York's zero-emissions credit program, which allows certain reactors to continue to operate. A modest credit, the report states, in the range of $12 to $17 dollars per MWh, would be enough to keep U.S. nuclear power plants open, which also helps retain key technical expertise.

Corradini also noted that the report indicates actions that government should consider to help deploy new nuclear technologies, including improving the design of competitive electricity markets. He said that although he has seen some improvement, he favors a more ambitious goal: to ensure technology neutrality in capacity markets, thereby avoiding a situation where the policies chosen will essentially determine the winners. Decarbonization policies should create a level playing field that allows all low-carbon generation technologies to compete on their merits. Other recommendations for government involvement that Corradini mentioned include establishing reactor sites where companies can deploy prototype reactors for testing and operation oriented to regulatory licensing, and managing high upfront costs for such projects, by, for example, sharing costs for R&D and licensing.

The next speaker was Eric Meyer, founder and executive director of Generation Atomic, a nuclear advocacy organization, who stated his appreciation for the work of the authors of the MIT report because it "makes my work as an advocate much easier." Meyer said that he never thought he would be involved in the nuclear world until he heard about advanced nuclear reactors and what they could mean for humanity, bringing in a new era of energy abundance. His desire to get involved led him to pursue a master's degree in advocacy and political leadership at the University of Minnesota and to learn how to talk about this challenging subject persuasively.


Photo: Greg Cohen/ProView Events LLC
Meyer

Meyer asked the audience to think about how public perception has affected the nuclear industry. He referred to a 2014 poll that put nuclear's global approval rating just marginally ahead of coal. While he is certain that nuclear's popularity has improved since then, Meyer said that he believes the public's negative perception has slowed the growth of nuclear power. This, he added, has led to other consequences, such as higher costs, a more difficult regulatory environment, and outright bans on nuclear plant construction, including in his home state of Minnesota. He said, however, that the problem was less about antinuclear sentiment in state legislatures and more about people not raising their voices to lift those bans. He also noted that public perception

tends to be influenced by journalists, who often write articles about nuclear power without mentioning its potential benefits regarding climate change and pollution, or the impact on power supply security and the local economy when a reactor is shut down.

Meyer, as a professional nuclear advocate, said that messages posted on social media must be memorable, simple, accessible, and different enough from others to gain people's attention. They should also be concrete and clear, easy to grasp, and credible, he added, and connecting an emotional element to them will make them more persuasive.

Meyer also described some unexpected advocacy successes. For example, over a year ago, he said, the then antinuclear Dutch government sent iodine tablets to members of the public. Then, about a month ago, Meyer and other nuclear supporters staged a pronuclear event in Munich—in the heart of antinuclear Germany—that was covered by the Dutch media. Surprisingly, he said, German antinuclear groups didn't show up at the event, and the Dutch media gave it positive coverage in Holland. A poll conducted in the Netherlands soon after the event showed that over 60 percent of those questioned were in favor of new nuclear plants in their country, which Meyer described as an amazing sea change in the Dutch public's view of nuclear.

Bradley Williams, senior advisor to the assistant secretary for nuclear energy in the DOE's Office of Nuclear Energy, spoke about recent efforts to engage with the public, particularly millennials. While there is a growing realization of the important role of nuclear power in addressing climate change and environmental sustainability, he said, there are other motivations for advancing nuclear energy. Currently, energy security is a very important topic across the administration, along with the need for reliable, resilient, 24/7 baseload generation. Nuclear, Williams said, is probably the best technology to meet those needs.

Photo: Greg Cohen/ProView Events LLC

Williams

With electricity demand remaining flat or even declining, however, variable and more flexible generation is penetrating the market as baseload production becomes less attractive, Williams said. As a result, new nuclear technologies are being developed to meet these and other changing customer demands, including for nonelectric applications. These nuclear technologies will help meet climate goals by decarbonizing the industrial sector, he added, and if they are used to provide hydrogen for fuel cells, they will also help decarbonize the transportation sector, making nuclear a game changer.

To implement a greater outreach program, Williams said, about two years ago the DOE created a communications office dedicated to issuing nuclear energy messages from a government perspective. In addition to making use of social media, the office is holding targeted events around the country called Millennial Nuclear Caucuses, designed to reach out to the younger population with the goal of engaging with them in order to understand their concerns and ideas, as they will be the future leaders driving the industry forward. The number of these events, which he said have been very successful, is being increased.

Outside Washington, D.C., the DOE is carrying the message about nuclear opportunities to states where nuclear plants are under threat of closure.

The DOE is also hosting "Lunch & Learn" events on Capitol Hill, featuring food from the appropriately named Atomic Wings restaurant to attract staffers, Williams said. These events, which are cosponsored with other organizations, take place about once a month. The most recent one, cosponsored with NASA, dealt with the work the DOE does to support space activities, something that many people aren't aware of, he said.

There is a lot of support for nuclear on Capitol Hill, both bipartisan and bicameral, according to Williams. Over a dozen bills concerning policies and measures that the DOE wants to make better known are now going through the legislative process, he said, using as an example the DOE's being given the authority to work on siting advanced reactor demonstration projects at national labs (as mentioned earlier by Corradini) and to move forward to determine the mission needs of the Versatile Test Reactor program. Also, the Nuclear Energy Leadership Act includes a number of important provisions, including purchase agreements for high-assay low-enriched uranium, the fuel needed for many advanced reactors.

Outside Washington, D.C., Williams continued, the DOE is carrying the message about nuclear opportunities to states where nuclear plants are under threat of closure. In Illinois, the DOE worked with labor unions and universities to organize and participate in events to inform policymakers of the consequences of the closure of the state's nuclear power plants. Illinois ultimately passed clean energy standards to keep nuclear plants operating, and similar activities have been carried out in other states as well, including Pennsylvania and New Jersey.

On the international scene, Williams noted, many meetings concerned with clean energy focus mainly on renewables, often excluding nuclear from the discussion. He said that in response, the DOE is taking action to level the playing field and push for technology-neutral discussions and policies. For example, Energy Secretary Rick Perry attended the Clean Energy Ministerial (CEM) forum in May 2018 in Copenhagen, Denmark, to ensure that nuclear—with the United States leading the way—was included in the discussions at that meeting. This led to the Nuclear Innovation: Clean Energy Future (NICE Future) initiative, which was officially launched at CEM by the United States, Japan, and Canada. NICE Future focuses on nuclear power as a clean energy option for reliable and resilient baseload electricity, he said, and for nonelectric applications, especially when deployed as hybrid nuclear-renewable systems.

Mohamed al Hammadi, chief executive officer of the Emirates Nuclear Energy Corporation (ENEC), was the final speaker. He provided an update on the United Arab Emirates' Barakah nuclear power plant project, where preparations are being completed for the start of the first of four Korean-supplied APR1400 units. Hammadi said that ENEC's mission includes professional development for the company and the UAE, and over the past 10 years it has been working to develop highly talented, highly qualified young professionals in parallel with developing its nuclear power program. The UAE and ENEC also understand the importance of the Barakah project outside the country, he said, as it brings hope for the nuclear industry globally going forward.

Photo: Greg Cohen/ProView Events LLC

Hammadi

The UAE launched its nuclear program in 2008 with a mandate to diversify its energy portfolio, noting nuclear plants' ability to provide a secure supply of baseload power. Nuclear power and its supply chain, Hammadi said, require a highly talented workforce that can achieve high nuclear quality, creating a niche market that provides a resilient and sustainable

sector of the economy. The construction of the Barakah plant began in 2012 with the first pouring of reactor foundation concrete for Unit 1, which is now 98 percent complete. The week before the ANS Winter Meeting, Hammadi said, he was at Unit 4 when the last major pour of concrete took place.

Hammadi then discussed highlights of the operational side of the project, for which two companies were formed by ENEC and its joint venture partner, Korea Electric Power Corporation: Nawah Energy, which will be responsible for operating and maintaining the power plants, and Barakah One, which will hold the station's assets and has financial responsibility for the project. Nawah, he noted, appointed Mark Reddemann, former CEO of U.S. utility Energy Northwest, as CEO to establish the nuclear safety culture needed to operate a nuclear plant and prepare the company to carry out its tasks.

Hammadi also spoke of other areas where the United States provided expertise, such as the Nuclear Regulatory Commission's assisting the UAE in establishing a competent nuclear regulator, the Federal Authority for Nuclear Regulation. He said that he is particularly impressed by the NRC's transparency in carrying out its responsibilities. ENEC is also engaging with the U.S. industry through the World Association of Nuclear Operators. Hammadi sits on the board of WANO's Atlanta Center, and he said that he considers it a privilege to engage with U.S. industry CEOs, as it allows him to learn what it takes to operate nuclear plants to the levels of performance and safety achieved in the United States.

Since the UAE launched its nuclear program, Hammadi said, hundreds of young Emiratis have graduated with degrees in nuclear science and engineering from universities in the United States and Korea. About 60 percent of ENEC's approximately 2,800 employees are from the UAE, and about 80 percent are under 30 years of age. They form a young, ambitious, and capable group, he said, who have the opportunity to grow and become competent professionals in their fields. "We are very proud of them," Hammadi said. He also mentioned the 40 or so other nationalities represented at ENEC that help create a dynamic and rich organization.

In conclusion, Hammadi said that the UAE and ENEC together have created a model for other countries with no nuclear experience to develop their own nuclear power programs.

Microreactor development

Microreactors have received a lot of industry attention lately, and the panel session titled "Micro Nuclear Reactor Concepts for Special Purpose Applications" generated a correspondingly high level of interest among the meeting attendees.


Kim

The session, which was organized by Nicolas Stauff and chaired by Taek Kyum Kim, both of Argonne National Laboratory, was designed to bring together people at the forefront of microreactor research, design, testing, and deployment to define the microreactor parameters, the needs of potential customers, and a path to a commercial market. The session was sponsored by the ANS Young Members Group, the Reactor Physics Division, and the Operations and Power Division.


Gehin

Jess Gehin, chief scientist at Idaho National Laboratory, started off the session with an overview of the Special Purpose Applications (SPA) technical area established in 2018 within the Advanced Reactor Technologies program of the Department of Energy's Office of Nuclear Energy. Gehin was filling in for Shannon Bragg-Sitton, INL's manager of systems integration for nuclear science and technology and the SPA technical area lead.

The SPA mission is to support companies and agencies developing microreactor concepts. According to a definition developed by the DOE, a microreactor produces 1–20 MWt and allows for factory manufacturability and assembly; transportability via truck, rail, aircraft, or boat; and self-regulation to enable safe operation under semiautonomous or autonomous operation. How high a reactor's power rating can go before it no longer qualifies as a microreactor is up for debate, however, as Gehin acknowledged.

Demonstrations of some microreactor concepts are expected within five years. What developers need to meet that accelerated time frame, according to Gehin, are access to high-assay low-enriched uranium (HALEU), an engineering-scale fuel fabrication capability, a demonstration site, and a flexible regulatory approach.

"An opportunity for this is the National Reactor Innovation Center, which was authorized as part of the Nuclear Energy Innovation Capabilities Act of 2017 that was passed and signed by the president," Gehin said. "It's ideally tailored to support reactor demos such as microreactor demos." The SPA team sees INL partnering with others to provide its experience in reactor operation and fuel fabrication and its existing facilities and greenfield sites for reactor demonstrations.

Nonnuclear engineering tests and demonstrations of full-scale or near-full-scale reactors could be conducted at INL prior to nuclear demonstrations. "Hopefully, within one to two years we'll have a capability that can be used by the reactor developers to precede their nuclear tests," Gehin said.

The HALEU called for in most microreactor concepts is in relatively short supply and high demand. "Hopefully, there is enough material available to enable those demonstrations to build a market case for somebody to start creating HALEU," Gehin said.

One way to reduce the amount of HALEU needed is to moderate the systems, so SPA is targeting the development of advanced moderators that are compact and effective. The project will also support the development of advanced heat pipes, heat removal systems, and power conversion systems.

Keith Bradley, director of National Security Programs at Argonne, focused his comments on the use of microreactors overseas by the Department of Defense. "I think that now is the time when the military is going to get serious about small reactors," he said. "I'm glad to see so much interest in the room."


Bradley

For Bradley, the numbers explain the DOD's motivation to use microreactors. Every three days, he said, the DOD consumes about 1 million barrels of oil, which exposes the agency to huge expenses when the price of oil rises. Delivering fuel to remote locations is costly as well. He said that there have been wildly different estimates about what it costs to deliver diesel fuel to the front line, ranging from $45 per gallon to $300 to $400 per gallon.

"A conservative estimate is that the DOD could save at least 60 percent in costs if it started deploying nuclear reactors overseas," Bradley said. "The DOD is not going to be as sensitive to the costs of electricity as the consumer market is, so if you want to push innovation and you don't want to have to be hindered by the cost of electricity, the DOD is a great potential customer."

The cost in dollars of delivering diesel fuel to forward-operating bases pales in comparison to the cost in lives. "In the six-year period between 2003 and 2009, more than 40 percent of the fatalities in Iraq were during fuel convoys, primarily

because of IEDs—improvised explosive devices—placed along defined paths," Bradley said. Fuel and water account for almost 90 percent of the volume of goods delivered to the front line. "We're losing soldiers just moving fuel to the front line, and as you can imagine, that's a great motivator for finding alternatives."

Bradley emphasized that military interest in microreactors is not a new concept. "There have been several programs in the past, and I think that the most fruitful and active one was mounted by the U.S. Army in the mid-50s," he said. "It was a program that lasted over 20 years, and roughly 13 to 15 of those years they were actually operating small reactors." The Army built eight reactors and designed a ninth—a liquid-metal reactor—that was never built. Then, as now, the Army made a distinction between transportable reactors and mobile reactors, and operated both.

Electricity produced by a microreactor at a forward-operating base would support traditional needs such as communications and information management; intelligence, surveillance, and reconnaissance; and HVAC. Bradley said that reactors providing 10 MWe could supply an installation's needs for the next 10 to 20 years, but he expects the military's requirements to increase as emerging, electricity-intensive technologies are adopted.

One such technology is additive manufacturing. "It's going to be a game changer for the military because it dramatically reduces the burden of the supply chain if you can deliver bulk materials and 3-D printers to the front line to make spare parts as you need them," Bradley said. While it will reduce the burden on the supply chain, additive manufacturing will increase electricity demand. He said that he also expects that electricity will be needed to produce, treat, or desalinate water, which will reduce the need to deliver water by convoy.

While nuclear fuel can replace diesel fuel for electricity generation at a military installation, ground and airborne vehicles will still use liquid fuels for some time. Bradley said that the possibility of using process heat from microreactors to make biofuels or synthetic fuel is "very attractive to the military." When electric vehicles and autonomous vehicles become commonplace, microreactors will be able to supply the electricity they need as well. "What we're going to see over time is the collaboration of systems that are driven by electricity and that communicate using electricity, and all of that is going to require considerably more electricity than what we have at the front line today," he said.

Electricity will also have a role in weaponry, Bradley said, and he anticipates that in the next 20 to 30 years, directed-energy weapons—such as high-powered microwaves, lasers, and jamming systems for electronic warfare—and electromagnetically launched weapons will be put in use. "I really believe that you need nuclear in order to really make directed-energy and electromagnetically launched weapons a practicality," he said.

The military will want to be able to move reactors using its existing transportation systems, according to Bradley, and that imposes weight and size limitations. "I think that this community needs to reflect on the fact that there are differences between transportable and mobile, and they do have different uses," he said. "I would advocate that the community tighten its lexicon and make these distinctions because they are going to have very real impacts on the design we're achieving."

> ***"What we're going to see over time is the collaboration of systems that are driven by electricity and that communicate using electricity, and all of that is going to require considerably more electricity than what we have at the front line today."***

Claudio Filippone is president and chief executive officer of HolosGen, which is developing microreactors that fit within a standard ISO container for transport by truck or aircraft and are operational on deployment.

Filippone

The Holos Quad is a 10-MWe Brayton system that can be coupled to an organic Rankine cycle to yield an additional 3 MWe. The Holos Quad consists of four identical, independent modules, each containing a portion of the core. "By themselves they're subcritical," Filippone said. "Essentially, you can move any of these modules, and by moving them you decouple them neutronically from one another. If you steal them, you have to steal all of them in order to make it work, otherwise it will remain subcritical."

Each of the four modules contains a fuel cartridge loaded with TRISO fuel pellets and operates with no moving parts. "It is a steady system where there are holes for a working fluid—in this case helium or CO_2—to go through, pick up the heat, and expand on the other side," Filippone said. "The working principle is essentially a turbojet engine, in which we took the combustor away and put in a nuclear heat source." He added that "we're not inventing anything new," which he anticipates will prove to be an advantage during licensing.

Just as the Holos Quad base configuration relies on four modules stacked together in one ISO container, multiple ISO containers can be clustered together to generate a total of 61–81 MWe. "There are different configurations we can make once we accept the idea that we can fragment the core," Filippone said. "The principle is the same."

A microreactor can be tested at its full size, which Filippone said is an advantage when it comes to testing, certification, and licensing. "Whenever regulators have a doubt about anything, you can say, 'Okay, let's test that,' and satisfy whatever requirement it is," he explained. "It would be too expensive to do that kind of validation on a large scale." A microreactor could be factory certified and then deployed around the world as an aircraft jet engine would be. "You don't recertify the engine every time you land in a different airport," he said.

"Economy of scale has to be revisited," Filippone said during a question-and-answer session that followed the individual presentations. Because the Holos Quad contains four identical modules, "one single ISO container is already a mini mass production. There is a threshold over which if you start to build a number of the same components—it's not a first of a kind, it's already an nth of a kind. Because of that you can drop the price dramatically, and also, these are small components, so you do not need to specialize the manufacturing equipment. Is a true economy of scale actually very small, with conventional tooling? I think we have a sustainable and competitive way to design a reactor."

Patrick McClure is the lead of the Kilo-Power project at Los Alamos National Laboratory. "At Los Alamos, we realize it's time to start building and developing reactors," he said. "We don't want to study them. Let's go build them."

McClure

LANL has been working on microreactor concepts since 2011 and recently tested a 1-kWe (4-kWt) KiloPower reactor at the Nevada Test Site. "What

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these reactors have in common is that they are self-regulating," McClure said. "They have very low power density, and because they are small and don't have a lot of decay heat, we think we can make them very much walk-away safe. In addition, we can test them in existing facilities using existing infrastructure."

KiloPower (1–10 kWe) is LANL's design for space applications, while MegaPower (25 MWe) adapts the same design to the DOD's requirements. Both feature heat pipe technology for passive heat transfer. "It's basically a sealed tube with a liquid metal inside," McClure said. "The liquid metal boils and the vapor moves up. It will condense on the condenser end, and then a wick will pull that back down to the evaporator. It will work in any orientation. It will work without gravity and will work against gravity, so it's great for a lot of applications." The reactor's fuel cartridge is a robust monolith with channels for heat pipes or gas flow.

When asked about the next step for KiloPower, McClure said, "Right now, NASA's thinking about a lunar mission. Our hope is that KiloPower will move to a lunar plant mission in the not too distant future."

Wesley Deason leads microreactor development at Ultra Safe Nuclear Corporation, which is developing the Pylon reactor for lunar applications. "Micro modular reactors are a paradigm shift for nuclear economics," he said. "We see 20 reactors in space by 2030, most of them being commercial-scale reactors.

Deason

A 1-MWe reactor would have a mass of 3,000 kg, which Deason said would fit on near-term moon landers being developed by commercial industry.

"Pylon reactors are reactors designed with conservative performance parameters and are scalable to multiple power levels," Deason said. "At a power of 10 kWe, we can fit this in a package of less than 1,000 kilograms, but we scale very well." A 1-MWe reactor would have a mass of 3,000 kg, which Deason said would fit on near-term moon landers being developed by commercial industry.

Chang-ho Lee, principal nuclear engineer in Argonne's Nuclear Engineering Division, works on the modeling and simulation of microreactors using a neutron transport code developed under the DOE's Nuclear Energy Advanced Modeling and Simulation program. "We are very excited to simulate these microreactors because a microreactor has irregular, nonstandard geometry, so there were no deterministic tools available," he said.

Lee's presentation focused on Proteus, a high-fidelity deterministic neutronics simulation code. "Rather than just neutronics code, it combines flexibility and capability for users," he said. Proteus has demonstrated its capabilities by simulating INL's Advanced Test Reactor and Transient Reactor Test Facility (TREAT), which have complex but well-understood geometries.

Lee

"Modeling the geometry of microreactors is very important," Lee said. The code provides options for the generation of cross sections, including MC^2 Monte Carlo–based generation, and cross sections generated within Proteus itself. Proteus is using CUBIT, developed by Sandia National Laboratories, to generate meshes. "Also, we developed in-house a mesh tool kit to provide more flexibility and capability for geometry and meshing," Lee said.

Proteus has been used to generate 2-D and 3-D representations of power flux distributions for microreactors, including Holos Quad and MegaPower. "We demonstrated the capability of Proteus to simulate this kind of reactor even though it may have a very complex geometry," Lee said.

The vigorous, accelerated development of microreactor designs, technologies, modeling tools, and end-user requirements bodes well for the eventual deployment of microreactors in numerous applications. Because designs and requirements are being developed simultaneously, however, there is no predefined path to a thriving commercial market. The process, in Filippone's words, has been "very painful."

"Depending on who you talk to, the requirements change on a daily basis," he said. "My advice is to get the right people to the table—some are in this room right now—and set these documents of requirements."

Closing the nuclear fuel cycle

The ANS Fuel Cycle and Waste Management Division sponsored the third in a series of panel sessions on the society's Grand Challenge of closing the nuclear fuel cycle. The ANS Nuclear Grand Challenges project was kicked off at the 2016 ANS Winter Meeting in Las Vegas, Nev., in an effort to drive conversations, both within the society and in the general public, about the issues that need to be addressed to ensure the advancement of nuclear science and technology. The fuel cycle Grand Challenge seeks to "establish the pathway that leads to closing the nuclear fuel cycle to support the demonstration and deployment of advanced fission reactors, accelerators, and material recycling technologies to obtain maximum value while minimizing environmental impact from using nuclear fuel."

Session organizer Sven Bader, a technical consultant at Orano Federal Services, opened the session by noting that the objective of the panel was to discuss and debate the pros and cons of federal versus private ownership of a spent fuel reprocessing/recycling plant in the United States. Among the topics covered in the discussion were proliferation and safeguards, wastes, regulations, and timelines. The panel also spent much of its allotted time discussing the costs associated with reprocessing and recycling.

In starting the discussion, Bader asked the panel who should take on the financial risks to build and operate a reprocessing facility and whether it is best approached as a public or private enterprise.

Francesco Ganda, a principal nuclear engineer at Argonne National Laboratory, began the discussion by noting that reprocessing projects outside the United States, such as those in France and Japan, have been successfully initiated with government assistance. In the United States, he said, there is a preference for private ownership and operation of large projects, adding that a case can be made for private management being more effective than federal management. The question, he said, is who is best suited for handling this enterprise?

Ganda

Jack Law, manager of the Aqueous Separations and Radiochemistry Department at Idaho National Laboratory, pointed out the importance of the federal government's pushing the technology forward to the point where it

Law

is mature enough that private enterprises can take it over. He cautioned, however, that large projects tend to end prematurely when government and politics become too involved. "It creates more of a political risk when there's too much involvement and funding from the U.S. government," he said.

Regarding the financial risks and rewards of building a reprocessing plant, Steve Nesbit, speaking as director of nuclear policy and support for Duke Energy, said that for a private company to become involved, there needs to be a high level of confidence that such an enterprise will succeed. He said that the current business climate, along with the experiences of recycling efforts elsewhere in the world, weigh against private investment. "From a practical standpoint," he said, "in today's environment, I can't see that happening."

Photo: Greg Cohen/ProView Events LLC

Nesbit

In looking for examples of where reprocessing projects have been successful, Nesbit said that France is the "shining star" for models that work. Noting the public/private interests behind the La Hague reprocessing plant, Nesbit said that France has been able to achieve "the best of both worlds" in terms of private and government involvement. "They have good business practices on one side, and they have the long-term investment that they needed through the government ownership," he said.

Emory Collins, senior technical advisor for advanced fuel cycles and isotope production at Oak Ridge National Laboratory, continued by discussing the cost barriers to reprocessing spent fuel in the United States. First, he said, regarding the levelized cost of energy, the majority of the cost of nuclear power is in plant construction, with no significant cost differences between the options of recycling/reprocessing and direct disposal. "From that standpoint, it is a neutral choice," he said. "The cost of building a reprocessing plant, however, would amount to an investment of approximately $25 billion, Collins said. While he conceded that this is a substantial amount of money, he noted that it is roughly equivalent to the cost of about three new power reactors. Furthermore, he said, such a facility would be able to relieve about half of the current nuclear fleet of its spent fuel.

Collins

Finally, in providing a utility perspective, Ben Carmichael, business development manager at Southern Nuclear, said that regardless of what model is used, his company wants to ensure that the Department of Energy meets its obligations under the Nuclear Waste Policy Act and takes possession of the current inventory of commercial spent nuclear fuel. "We are interested in what [other options] can be more attractive economically, but we do not want to see anything done to invalidate the obligations that exist for our six operating units right now," he said.

Waste management

With the Yucca Mountain Project and the U.S. high-level radioactive waste program at a standstill, the issue of HLW disposition remains a drag on the nuclear industry and a financial drain on the government. The appropriately named panel session, "Used Fuel and High-Level Waste Management: The Long and Winding Road," addressed the current and evolving status of the geologic disposition and interim storage of used nuclear fuel.

Lake Barrett, who has traveled many miles on the HLW road, led off the panel discussion by noting the progress made so far in the U.S. waste management program. "It has come a long way in the last 50 years, and it still has a long way to go," he said. Now an independent consultant, Barrett served as head of the Department of Energy's Office of Civilian Radioactive Waste Management from 1993 to 2002 and is well known for his involvement in the early response to the Three Mile Island-2 accident in 1979.

Barrett

Noting that there have been "political bumps," both major and minor, along the road to licensing the Yucca Mountain repository, Barrett said he believes that "things are going to get better." Regarding the fight over the Nevada repository for used nuclear fuel, he said that he does not see the state winning, adding, "There is no realistic substitute for Yucca Mountain." Barrett said that he thinks the U.S. Congress will appropriate money for Yucca Mountain licensing sometime in 2019.

Barrett also said that consolidated interim storage options for used nuclear fuel will be an important part of the country's waste management program, noting that there is more support for private interim storage initiatives. "I think the private companies need to be the leaders now, and the federal government needs to support that," he said.

To help advance such interim storage initiatives, Barrett said, the DOE needs to focus on working with private companies on developing the necessary business structures and a consensus framework for siting and developing storage facilities. Within the next three years, he said, the DOE should report to Congress on the state of Yucca Mountain and interim storage licensing, adding that Congress will then need to make a decision as to how the program will move forward. "Everyone should work together to obtain the necessary statutory support to complete this," he said.

Building a regulatory framework for accepting used fuel and Greater-than-Class C (GTCC) waste at an interim storage facility or permanent repository was discussed by the session's next speaker, Adam Levin, former director of spent fuel and decommissioning at Exelon Generation.

Noting the challenges in long-term waste management planning and the lack of political support for licensing a geologic repository, Levin said, "I actually see the DOE's delay as a golden opportunity to create a framework for handling spent fuel and Greater-than-Class C waste."

Such a framework, Levin said, hinges on establishing an acceptance queue to remove used fuel and GTCC waste in the order in which plants have been retired, with shutdown plants being given highest priority for waste removal. He added that fuel and waste should be removed in two phases, with the first phase concentrated on plant sites where decommissioning has been completed and the second phase focused on plants that are close to shutting down. Levin's opinion is that it is possible—using state-of-the-art fuel handling and transportation systems—to remove used fuel and GTCC waste from a nuclear power site within 10 years of a plant's being shut down.

To help advance interim storage initiatives, the DOE needs to focus on working with private companies on developing the necessary business structures and a consensus framework for siting and developing storage facilities.

Ben Holtzman, a senior project manager with the Nuclear Energy Institute,

provided an industry perspective on used fuel and HLW, discussing how used fuel management fits into NEI's recently developed industry-wide strategy that focuses on preserving the current nuclear power fleet, creating sustainability through an improved regulatory framework, deploying innovative nuclear technologies, and competing in the global nuclear energy marketplace.

Holtzman said that the nation's stranded fuel affects the industry's ability to sustain its nuclear fleet, noting that about 81,000 metric tons of commercial used nuclear fuel is currently in storage in the United States. "This is something that we, as an industry, don't want, people in these communities don't want, and it's something that should really drive a lot of political support for [moving the fuel]," he said.

NEI is working to enact "used fuel principles" in an effort to describe the problem and determine what can be done to solve it, Holtzman said. These principles include protecting the Nuclear Waste Fund and using it as intended by the Nuclear Waste Policy Act (NWPA), completing the licensing of the Yucca Mountain repository, and reforming the management of the federal HLW program. Holtzman included among these principles NEI's support for the development of a consolidated interim storage facility, noting that such a facility would take pressure off progressing with Yucca Mountain. At the same time, he said, preserving the Yucca Mountain option takes pressure off interim storage facilities by demonstrating that such sites will not be long-term solutions to used fuel disposal. "The idea is that progress on one is going to help progress on the other, because there is a common interest," he said.

Holtzman ended his talk with a brief mention of the midterm elections and how they will likely affect the country's HLW program. He pointed out that the Nuclear Waste Policy Amendments Act, which the House of Representatives had recently passed by an overwhelming majority, demonstrates that there is large bipartisan support for moving forward. With the Democrats taking control of the House, however, it is uncertain whether new legislation will continue to move forward, he said, adding that it is likely that progress will be made only on interim storage measures and not on Yucca Mountain funding or licensing.

The politics of used fuel was taken up by the session's final speaker, Eric Knox, vice president of strategic nuclear development for AECOM, who began with a brief history of HLW management in the United States, beginning with the 1957 recommendation by the National Academies of Science that deep geologic disposal is the best option for used fuel. He also mentioned the 1987 amendment to the NWPA, often referred to by opponents as the "screw Nevada bill," which designated Yucca Mountain as the sole repository site to be considered. Regarding the political motivations behind the bill, Knox said, "It was a political decision, absolutely, but it was a technically informed political decision." Knox added that a series of reports established the technical basis for designating the site as the preferred alternative.

The lesson of waste management history, Knox said, is that "there is a record of progress and success when a decision is made and we stick with it." The difficulties arise when politicians change course and nothing gets done, he said, adding that constantly changing direction affects the country's ability to move forward with its program and erodes public confidence. "It is the politics that prevents what we know is the best thing to do from happening," he said.

While Knox did not offer any definitive paths around the impediment of politics, he did say that time is ultimately on our side. "My position is that a 10-, 15-, 20-year delay is not a death knell for the program," he concluded.—*Susan Gallier, Tim Gregoire, Dick Kovan, and Michael McQueen* NN