TOPICAL MEETING

HTR 2016: Finding pathways to commercialization

High-temperature reactors have their own challenges, including how to move from concept to demonstration to commercialization.

The opening plenary session of the 8th International High Temperature Reactor Technology Topical Meeting (HTR 2016), held in conjunction with the ANS Winter Meeting in Las Vegas, Nev., last November, was introduced by the meeting's general chair, Finis Southworth, assistant executive director of the Next Generation Nuclear Plant (NGNP) Industry Alliance.

In his introduction, Southworth took the opportunity to set out his list of challenges for the HTR community, in anticipation of the ANS President's Special Session, "Identifying the Nuclear Grand Challenges," scheduled for later that day. His list included the following:

- Obtain a license for a combined-cycle HTR plant at a greenfield site within three years and build it within four years.
- Ensure that HTRs are designed to be inherently safe (that is, "walk-away safe"), not just passively safe, for 48 or 72 hours.
- Keep emergency planning zones to under a half-mile radius.
- Implement a spent fuel disposal program.

To meet this last challenge, Southworth recommended that Congress pass legislation implementing the recommendations of the Blue Ribbon Commission on America's Nuclear Future, which would put the country on the road to a solution almost immediately.

In the opening presentation, John Kotek, acting assistant secretary of the Department of Energy's Office of Nuclear Energy (he has since been named vice president for policy development

Southworth

Kotek

and public affairs at the Nuclear Energy Institute; see People, page 66), explained how the DOE is working to reinvigorate and restructure the advanced reactor programs to lead to greater success in commercializing technologies. "We need multiple pathways going forward," he said, noting that there are many competing advanced reactor technologies, some of which, it is hoped, will achieve commercialization. He also said that it is time to deconstruct the nuclear value chain into its various elements to look for opportunities to reduce costs, a process that has not yet been carried out for advanced designs. That, he said, will likely identify over-conservatism in many areas where measures can be taken to develop more competitive systems.

One way the DOE is addressing the challenge, Kotek said, is through its Gateway for Accelerated Innovation in Nuclear (GAIN) initiative. Launched at the end of 2015, its aim is to provide the nuclear community access to the technical, regulatory, and financial support necessary to move new or advanced reactor designs toward commercialization. A particular effort undertaken as part of GAIN is to determine what the communities of innovators need from the government. For example, Kotek said, with the assistance of the Electric Power Research Institute and the NEI, a series of workshops has been held to bring innovators together in the various reactor areas to determine whether there is a common research agenda that the DOE can support. The workshops have led to recommendations for incorporating additional activities into the DOE's basic research programs to benefit multiple designs in a technology area.

Kotek noted that the DOE is also making a case for why nuclear needs to be a robust part of an expanded clean energy research, development, and demonstration portfolio, and not just by engaging the national laboratories and universities. There are companies out there, Kotek said, that see potential benefits even decades from now and are spending their own money to develop and bring advanced products to market.

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Next up was Kam Ghaffarian, founder and chief executive officer of X-energy, which is developing the Xe-100 pebble bed HTR. Ghaffarian challenged session attendees to focus on the deployment of their products. "We need to put a vision out there that in the next 10 years we are going to be building an advanced reactor," he said.

Ghaffarian summarized the fundamental energy problem as a combination of climate change, pollution, and population growth. Getting from the current situation to an environment that is clean, safe, secure, and affordable must involve nontraditional thinking, he said, and the way of thinking of even 10 years ago will not solve today's problems. His solution is advanced nuclear reactors.

Ghaffarian warned, however, that while having many possible pathways may be attractive, the DOE cannot afford to sponsor multi-option programs. It is necessary to be selective in terms of the technologies pursued, and the best way to do that is through competition. There is already competition in the light-water reactor area, he said, and now it is time to have competition in advanced reactors to push forward the good ideas and then create a cost-share program to support them. This is the only way forward, he added, because government help will be needed to make it happen.


Ghaffarian

At X-energy, a team was formed to focus on finding ways to deploy its advanced reactor. Collaboration and partnership will be part of the solution, he said, and X-energy has recently signed two memoranda of understanding, one with Southern Nuclear and the other with Burns & McDonnell, focused on deploying an HTR. Further MOUs are expected with organizations in other countries.

Ghaffarian noted that a new way of thinking is also needed in how the Nuclear Regulatory Commission handles the licensing of advanced reactors. In particular, he said, greater clarity is needed on the time required for and the cost of processing applications for advanced reactors. These should be determined through the conduct of an analysis, he noted, and once that is done, the government should be responsible for any extra costs that might be incurred.

The next speaker was Crzegorz Wrochna, the Polish government's director for HTR deployment, who also represents the European Union's HTR community as chair of the Nuclear Cogeneration Industrial Initiative (NC2I), which aims to commission an HTR cogeneration prototype within 10 years. There is a large potential market for cogeneration in the developed world, Wrochna said, and he believes that a window of opportunity is now opening up for HTRs in the European Union.

The existing market for industrial heat applications in Europe shows that 200 MW thermal covers a large number of users, Wrochna said. Adding some megawatts for electricity production gives a typical range of between 200 and 350 MW thermal as a suitable size for a reactor. For those applications requiring only low temperatures (that is, below 250 °C), which include, for example, district heating, the manufacture of pulp and paper, and desalination, LWRs would be sufficient. For applications needing higher temperatures of up to 1,000 °C, however, including industrial cogeneration and hydrogen production, HTRs are particularly suitable.

Wrochna said that he believes that the HTR provides a good solution for satisfying Poland's need for industrial steam energy and could be relatively easy to introduce there. The country has a large number of chemical processing plants and refineries that use heat generated by domestically produced coal or imported natural gas. These facilities also produce power, he said, providing significant additional revenue to the companies, which would be comfortable owning or investing in nuclear power in place of fossil-fueled boilers.

Under the Polish government's latest nuclear road map, the longstanding plan has been to build two LWR stations, with the first starting operation around 2030. The startup of a first HTR soon after that is now included. In the meantime, something even newer has been added to the plan: the construction of a small, 10-MW thermal HTR, called a U-Battery, to be ready by 2025. To be located at the country's National Centre for Nuclear Research, this facility will provide operator training and will also facilitate regulators in the licensing of a large commercial HTR. A letter of intent for the supply of the U-Battery was signed with Urenco, the lead organization in the U-Battery consortium, in May 2016.

On the international front, Europe's NC2I and America's NGNP Industry Alliance established a transatlantic cooperation framework called the GEMINI Initiative under an MOU signed in June 2014 that includes undertaking projects, representing the technology before government authorities, and taking other actions to promote advanced reactors. A primary goal is to undertake two first-of-a-kind projects in the United States and Europe, based on a reference design, tailored to the site and national requirements. Wrochna also referred to the efforts of the British government to regain a position as a vendor country via the small modular reactor (SMR) route. As a step toward developing this capability, the U.K. government announced a £250-million (about $307-million) SMR competition in March 2016 for which the NC2I put in a proposal on behalf of NGNP/NC2I.

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These international plans were further discussed by Chris Hamilton, executive director of the NGNP Industry Alliance, who remarked that while the United States looks to the HTR primarily to produce electricity, most other countries stress its value in cogeneration, hydrogen production, and other non-power applications. This provides the HTR a useful distinction from LWRs for promotional and marketing purposes.

The NGNP Industry Alliance's approach is to focus on HTR deployment activities, but currently it is primarily working on necessary nondeployment activities, such as upgrading the HTR business plan, undertaking an exercise to quantify conservatism used in an analysis of an HTR depressurization event (being conducted at Texas A&M University), and evaluating four sites for advanced reactors.

The reference design chosen for development is Areva's 625-MW thermal prismatic core HTR. A relatively large reactor capacity was chosen because of the low price of natural gas. This size, however, also works for typical U.S. chemical plants, which are substantially larger than those in Europe. Hamilton also stressed that even at this size, the HTR fuel is so robust that it can tolerate loss of pressure, loss of flow, and loss of coolant without safety being compromised, unlike LWRs. He also noted that the challenges faced by the HTR designs examined are not very technical. The main ones are financing and first-of-a-kind costs, along with licensing uncertainty, which all advanced reactors face, as well as low natural gas prices.

But there are also opportunities, Hamilton said. Unlike other Generation IV concepts, the HTR is a mature technology, with several reactors having been licensed and operated, a proven fuel, and a regulatory system largely in place. Internationally, there is a lot of interest in the HTR backed up by several projects and national programs, driven forward by the need for a non-fossil-fueled high-temperature heat source for industrial cogeneration and other applications.

HTRs are projected to be competitive with natural gas–fueled power units at moderate gas prices. A detailed analysis done by the DOE and national laboratories found that an HTR for cogeneration would be competitive at $6 to $8 per million Btu.

Finally, Hamilton noted that although the technology is not revolutionary, its potential is, given that it can provide a source of energy to displace fossil fuels in a way that is not possible in many applications. Today, he said, high-temperature process heat applications that currently use fossil fuel produce about 20 percent of world carbon dioxide emissions. The HTR also uniquely offers the potential of clean, high-efficiency hydrogen production.

While most of the innovative systems presented at this meeting exist mainly on paper, China's Zhang Zuoyi, chief scientist for the High-Temperature Reactor–Pebble Bed Module (HTR-PM) demonstration project, could speak of the very real experience gained in a project nearing completion. The HTR-PM, which is under construction at Shidao Bay in eastern China's Shandong Province, consists of twin 250-MW thermal (100-MWe) reactor units driving a single turbine. Zhang is also director of Tsinghua University's Institute of Nuclear and New Energy Technology (INET), which is where the 10-MW thermal HTR-10 test pebble bed reactor is located.

Zhang described the project's evolution since the start of construction, which officially began in December 2012, with operation scheduled for 2017. He also presented two videos showing construction activities, including the placement of one of the two reactor pressure vessels, one of the heaviest ever manufactured. Among the many challenges the team faced, he noted,

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was having to deal with a very demanding safety authority.

At the time of the meeting, construction work was still focused on installing components, the main ones being the reactor pressure vessels, reactor metallic internals, graphite blocks, the fuel handling system, control rod drive mechanisms, small sphere absorption systems, and helium circulators. Zhang noted that delays in the installation of the steam generators had set the schedule back by about seven months, although grid connection was still expected in 2017. The main work needing to be completed on the steam generators is to connect the main inlet and the outlet pipes.

Zhang also described the extensive testing of key components, focusing on the helium circulator, the fuel handling system, and the steam generators. The critical helium circulator uses a magnetic bearing, which, he said, made it a world first, requiring extensive testing, first in nitrogen and then helium. A conventional backup was also built in case of problems.

The full-scale helium circulator test carried out at INET included 50 life cycles using helium. During each cycle, which involves moving from cold startup conditions to hot full-power conditions, 10 transient events were initiated, with a total of 500 carried out over a six-month period ending in May 2016. There was also an extreme condition test with helium. These costly tests were done, Zhang said, because the decision had been made to follow the same procedure that was used for testing the AP1000 pump in the United States.

The testing of a full-scale fuel handling system, a key technology for a pebble bed HTR, involved 500 hours of automatic operation of the system under hot conditions with helium at 7 MPa pressure. That test was completed on October 8, 2016.

Zhang also remarked on the many difficulties that had to be overcome in completing the tests. As an example, he noted that nearly a year was spent solving problems with the helium seal on the helium circulator.

Zhang also referred to the latest experience with the HTR-10 test pebble bed reactor at INET in support of the HTR-PM project. In the last couple of years, the focus there has been on maintenance activities. For example, the helium circulator, which was highly irradiated, was removed for inspection. The control rod drive mechanism was also inspected and maintained. Over the last year, the HTR-10 saw almost 100 days of continuous operation, he said, and it is in good condition.

Regarding the fuel, a demonstration production facility capable of producing 100,000 fuel spheres per year has been in operation at INET since 2010, and a commercial 300,000-sphere-per-year plant has been built, with production starting in August 2016.

In China, Zhang said, HTRs are considered supplementary to pressurized water reactors, with one likely future role for them being to replace coal-fired plants in populated regions, particularly in the eastern part of the country. HTRs of similar size should be able to use some of the infrastructure of the existing generating plants in many places. HTRs also would have a role in cogeneration and hydrogen production.

For commercializing the technology, Zhang described the HTR-PM600, consisting of six reactor modules connected to one steam turbine. He also showed a configuration with the six reactor modules in a circle, which would produce the same footprint as a 600-MWe Generation II PWR built in China. This, he said, should lead to considerable savings.

Efforts are continuing to reduce the costs of subsequent HTR-PM600 plants in order to compete in the market. Zhang said that measures such as increasing plant power to 650 MWe and batch ordering of reactor modules would reduce costs to just 10 to 20 percent above the cost of PWRs.—*Dick Kovan* NN