ATF: Accelerated innovation through collaboration

During the ANS Winter Meeting, a panel session focused on the development and deployment of accident-tolerant fuel.

The panelists at the General Chair's Special Session during the 2018 ANS Winter Meeting, held November 11–15 in Orlando, Fla., described a singular success story from several perspectives. Their message, simply put, was that rapid nuclear fuel innovation within a regulatory framework is achievable.

From design to deployment, the traditional approach to nuclear fuel development takes 20 years. The 18-month development, qualification, and deployment of test rods of Global Nuclear Fuel's (GNF) IronClad fuel cladding, the focus of the special session, has set a new benchmark.

"Accident Tolerant Fuel—A Case Study of Accelerated Innovation Through Collaboration" was moderated by Johnathan Chavers, manager of BWR fuel engineering for Southern Company, who was introduced by Daniel Churchman, general chair of the ANS Winter Meeting and fleet engineering director for Southern Nuclear.

The sustainability of the U.S. nuclear fleet depends on innovation at a pace that allows commercial plants to remain economically competitive with other energy technologies, Chavers said. "The commercial nuclear power sector sees enough potential in the accident-tolerant fuel program that we are driving and lobbying for an accelerated timeline for testing, analysis, and licensing, with the goal of final deployment of accident-tolerant fuel technology across the existing reactor fleet by the mid- to early 2020s," he said. In February, Southern Nuclear introduced test fuel rod segments featuring GNF's ARMOR nuclear fuel cladding at Hatch-1, an 885-MWe boiling water reactor located near Baxley, Ga.

Photo: Greg Cohen/ProView Events

The panelists for the General Chair's Special Session on accident-tolerant fuel were (from left) Johnathan Chavers, Amir Vexler, Kurt Terrani, Aladar Csontos, and Kemal Pasamehmetoglu.

Increasing the accident tolerance of light-water reactor fuels became a priority of the Department of Energy following the March 2011 Fukushima Daiichi accident. Three fuel suppliers—General Electric, through GNF; Westinghouse, in partnership with General Atomic; and Framatome (known at the time as Areva)—received funding for industry-led cost-shared projects when Congress funded an accident-tolerant fuel (ATF) program within the DOE's Office of Nuclear Energy in 2012.

Kurt Terrani, a senior staff scientist and leader of the Nuclear Fuels Materials Group at Oak Ridge National Laboratory (ORNL), was involved in obtaining data on potential fuel cladding materials. He spoke about "what went right" in the DOE's accelerated program to develop and deploy ATF lead test rods.

According to Terrani, the research process at ORNL started with one question: "How can we impact accident progression to reduce the burden on reactor safety systems?"

The oxidation of zirconium-based cladding on fuel rods at high temperatures is a chemical reaction that produces heat. While decay heat in a reactor is a function of the reactor's power level, added heat from oxidation could be avoided. "We want to reduce the burden on cooling and on the safety system by reducing the amount of heat that is being generated," Terrani said. DOE researchers identified several materials that could serve as oxidation-resistant films for fuel rods,

including chromium oxide, aluminum oxide, and silicon carbide claddings.

"We brought to bear a broad range of capabilities and expertise across the DOE complex, and also across the industrial complex," Terrani said. "We don't see that very often. Usually you see work at one area focusing on one tool." Work was done using computational facilities at Idaho National Laboratory, materials processing at ORNL, and radiation testing at INL's Advanced Test Reactor and ORNL's High Flux Isotope Reactor. Examinations in DOE hot cell facilities preceded the handover of the technology to fuel vendors.

Terrani described the cladding development process as "non-Edisonian." Instead of producing numerous prototypes and then testing their function, he said, "We started out designing things that we knew were going to work. We set about proving, generally and with data, that these are in fact functional systems."

When the DOE first made the development of ATF fuel a priority, there was a lot of skepticism from U.S. and international leaders about its feasibility, Terrani said. "I'm being very honest with you—I used to almost get laughed out of the room in 2012 for saying, 'We're going to consider cladding that's not zirconium.' That was considered a pretty funny joke back then."

That had changed by the time he attended Top Fuel 2016, in Boise, Idaho. "I was sitting in the back of the room," Terrani recalled, "and I saw all of a sudden that it's now the industry that is leading this effort."

During a question-and-answer session that followed presentations by each panelist, Terrani was asked if accident tolerance requires a non-zirconium fuel. He explained that there is a difference in the extent of accident tolerance benefits that could be gained. "The challenge is beyond- design-basis accidents—it's a broad territory with a lot of scenarios. I wouldn't say that you have to move away from zirconium exclusively to gain any accident tolerance." One evolutionary approach is to apply oxidation-resistant coatings to the surface of zirconium-based alloys, he said. Given a very severe accident, however, the coating can eventually "float away" and "you're back where you started."

Aladar Csontos, a technical executive at the Electric Power Research Institute, spoke about EPRI's role as a "technology accelerator" that takes input from member utilities, communicates with national laboratories, other research organizations, and the Nuclear Regulatory Commission, and then "transfers that technology to the real world."

Csontos mentioned the traditional 20-year time frame for fuel development and qualification. "We can't wait that long," he said. "In a year and a half we have lost four plants. What does that tell you? The need for innovation and acceleration for advanced fuels is very key to getting a success story long-term for accident-tolerant fuel.

"The benefits of accident-tolerant fuel are amortized over the remaining life of the plant," Csontos said, "and as plants start to shut down or move into their decision-making for subsequent license renewal, we need to be there as a voice to tell them that this is what you're going to get with accident-tolerant fuel."

Over the last year and a half, EPRI worked with a task force to create "ATF Valuation 1.0," which incorporates a safety benefits analysis and translates those safety benefits to a business case. The main benefits of ATF so far, according to Csontos, have been in fuel cycle economics: higher enrichment and higher burnup, which enable operational flexibility and offer the potential for a two-year refueling cycle to improve efficiency and economics.

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"We would not have gotten to a consensus with the safety benefits without this collaboration that includes academia, the national labs, utilities, third-party research organizations, and the NRC," Csontos said.

"ATF Valuation 2.0," which will be released in 2019, includes an analysis of additional ATF benefits based on site visits to the Catawba, Hatch, Limerick, Palo Verde, and Vogtle plants that EPRI made with vendor stakeholders. "We asked them what their pinch points were in their reactor operations and how accident-tolerant fuels or advanced fuels could help," Csontos said. He said that utilities frequently ask, "How can it help operationally? How can it help shorten outage time?"

EPRI has concluded that the deployment of ATF offers potential economic benefits, and the organization's next step, planned for "ATF Valuation 3.0," will be to analyze applications of ATF in specific reactors. "What we've found . . . is that the benefits are not really generic," Csontos said. "There are specific examples of specific pinch points for each individual reactor at each site that we want to talk about."

The next speaker, Amir Vexler, chief executive officer of GNF, said that there is no better teacher than bad experience. He posed several questions: "How can you understand failure? What did not work? How do you know that your idea is worth following?"

Vexler emphasized that in the case of GNF, a for-profit company, "If we have a failed program that we sank half a million into—that is devastating to us. There are a bunch of other programs that are not going to get funded somewhere else. We are very driven to say 'We're not going to fund anything like that anymore.' So understanding the mechanisms of failure and what failed is very critical." In the past, he said, the process of turning ideas into products was ad hoc, with no guarantee that the idea being pursued was going to find a customer.

"The biggest assumption that we make when we develop a product is that there is actually going to be interest in it, that somebody will actually pay money for it," Vexler said. "We have warehouses full of devices and ideas that we put a lot of money into, and when it came to the last stage of presenting it to our customers, they said, 'Well, this is really good, but I don't think we're going to pay for it.' That's horrible. And so the partnership that we created gives me the assurance that at the end of this entire process, there will be a customer."

The first fueled ATF lead test assembly featuring ARMOR-coated rods was loaded in Hatch-1 on February 13. ARMOR is a coated rod technology designed by GNF to protect fuel rods from debris fretting, which causes fuel failures. IronClad is GNF's ferritic steel cladding, co-developed with ORNL and GE Global Research under the DOE's ATF program. Exelon's Clinton plant will load IronClad test rods in 2019.

GNF is being challenged by utilities to innovate rapidly. "At no time in the past have we seen plants shutting down because they were economically unviable," Vexler said. "That is devastating to the industry." Under the circumstances, he said, fuel vendors must take a long-term view. "The aspirational value of what you're developing has to be more than 'I want to make more money.' That does not work as well as striving for making a reactor safer or striving for making our industry more competitive."

Kemal Pasamehmetoglu, associate laboratory director for INL's Nuclear Science and Technology Directorate, proposed an alternative to the traditional 20-year time frame for fuel development. "It takes too long," he said. "It turns off the investors, it turns off the researchers."

Pasamehmetoglu proposed shifting to a new paradigm—a 10-year time frame

that he said could be developed under the OECD Nuclear Energy Agency's Nuclear Innovation 2050 program. That new paradigm would cover phenomena identification, the design envelope, initial simulation and uncertainty, a phenomena identification and ranking table, analytical experiments, model validation/uncertainty reduction, and design optimization, followed by integral tests.

Analytical experiments would be undertaken during the first three or four years of work to support modeling and simulation. "We need to work closely with the utilities and the regulators to make sure the analytical experiments—the way they are designed, the way they are conducted—answer the critical questions," Pasamehmetoglu said.

He posited that not all of the analytical experiments need to be conducted at a full length and time frame. He named a number of phenomena of interest, such as grain boundaries mobility and fission product transport, that are already well understood. "Those phenomena appear at the small timescale," Pasamehmetoglu said. "In many cases, that is not a three-year experiment. I truly believe that over many decades having worked with many different fuels, we do know the phenomena that we worry about.

"This paradigm would be very applicable to cases where we design reactor systems starting with fuel, building the reactor around the fuel to take advantage of the strengths of that specific fuel and compensate for what we've missed with the rest of the reactor design," he said.

During the question-and-answer session, Pasamehmetoglu was asked to comment on the prospects for international collaboration in fuel development. "In the early days of technology development, I think [collaboration] works really well along with the competitive markets," he said. "I'm hopeful that there will be a small group of countries that will come together with dedicated funding for this and really start running this as a project."

Chavers returned to the lectern to make a presentation from Southern Nuclear's perspective as a fuel customer. "We have found that innovation independent of external partners is less cost-effective and is riddled with obstacles," he said. Instead, Southern has embraced collaborations with government, other utilities, universities, and all three fuel vendors in the DOE's ATF program.

"A lot of what we used to do was very transactional," Chavers said. "What we're doing now is a paradigm shift. . . . We're engaging very early—and not just Southern Nuclear, but other utilities such as Exelon and Entergy—we're all engaging in a partnership, and it's much more collaborative than transactional. . . . Before this accident-tolerant fuel program, we at Southern Nuclear had never directly worked with a national lab to associate something that they're doing with one of our reloads."

Southern Nuclear's pursuit of ATF is driven by economics. "We really view accident-tolerant fuel technology as an enabler for us to get other things that we want or require, such as increased enrichment, increased burnup, and increased operational margins. All of this is to extract value to create an economically viable product."

As the session drew to a close, Csontos was asked a question that may have been on the minds of several attendees: "Will ATF save the nuclear industry, or just a few plants?"

"If you're already at risk of shutting down, ATF is not going to be there in time to save you," he said. "But for those plants that are going into subsequent license renewal or are thinking about going into subsequent license renewal, understanding the economic benefits and what it will cost to get there, and looking into the amortization of those benefits economically over the remaining life of the plant, I think will help those plants stay afloat longer."—*Susan Gallier* NN