Advanced reactors: An endless landscape

by E. Michael Blake

The term "advanced" is, of course, relative, no matter how it is applied. Power reactors that have been in operation for decades were once seen as advanced beyond older designs. Those same reactors that produce our electricity constitute, in this era, the level of the ordinary, from which new designs are considered advanced. Because there is such a large pool of nuclear scientific and engineering talent worldwide, it seems reasonable to project that what we see as advanced now could be outstripped decades later by even greater advancements.

The larger term "advanced reactors" is used in this special section to indicate designs and concepts beyond most of the ones that are being built now. Because so much has been written about them, both in *Nuclear News* and elsewhere, we are drawing the starting line just beyond reactor models that are generally thought of as "evolutionary," with one exception: The AREVA-Mitsubishi collaboration, ATMEA1, is included because we have hitherto given it relatively little coverage, and because it is something of a departure for two vendors whose other designs are known for extensive engineered features and high power ratings.

The following articles and their accompanying graphics were provided by the organizations developing these reactor models, although to varying degrees they have been modified by (or under the direction of) *NN*'s editors. We will be the first to concede that these articles do not cover all of the ground in advanced reactor development, and any attempt to list every design could run far beyond the interest level of any reader, depending on how the word "design" is defined. Nor do we think that a mention in *NN* guarantees a reactor model's progress to reality, just as the lack of such a mention will not guarantee a model's plunge into oblivion. (Also please note that the inclusion of these particular articles in *NN* does not constitute an endorsement by the magazine or by the American Nuclear Society.)

It can be said that the following articles cover prospects that have gone through considerable research and development, presumably enough to reveal whether the models' core concepts are based on deal-breaking flaws. Designs have changed and prospects have been reassessed, but for every model in these articles, there continues to be confidence, inside the developing organization and outside of it, that the effort can produce a worthwhile product.

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As for the models, designs, and concepts that are not in these articles, here is a brief summary of what has gone before and what may be on the way. We apologize in advance if we have left anything out, although we stand by the following reasons for keeping a velvet rope in place. Excluded are any concepts that 1) can deliver on their promised benefits only through the creation of a worldwide, treaty-altering system of reprocessing and waste disposal facilities; 2) are being advanced by a few people who are looking for crowdsourced funding; 3) pose serious challenges for licensing or regulatory approval, which are blithely dismissed by the proponents; and 4) are being championed mainly to reverse what are asserted to be historical wrongs that supposedly arose from closed-door decisions made early in the Atomic Age, with money purportedly beating down science and justice.

Old-school advanced

The **liquid-metal fast-breeder reactor (LMFBR)** has a long history, some of it involving energy production, but it certainly remains an advanced concept, given that nearly all other nuclear energy has come from water-cooled reactors and single-use fuel. While there is active deployment now taking place in Russia, with the **BN-800** at Beloyarsk reported to be in a startup phase, in most other programs there have been substantial problems that have overwhelmed the potential benefits of liquid-sodium heat transfer and the transformation of uranium-238 into plutonium-239. France's **Super-Phénix** generated power during only six of its 11 years of operation, with a total capacity factor of about 8 percent, and no other LMFBRs followed it. Japan's **Monju** has twice been halted before initial startup because of technical issues. A prototype fast-neutron reactor is being developed in China, and farther along is the **PFBR** in India. It is intended as a 500-MWe power plant, and while major construction is said to be essentially complete, there is not at present an announced target date for startup.

Almost any gas-cooled reactor concept would have to count as advanced, because there are so few gas-cooled units now in operation (all of them in the United Kingdom, where they are ultimately being retired). For several years, there was a broad-based effort to promote the **Pebble Bed Modular Reactor (PBMR)**, derived from concepts initiated in Germany and developed further by the South African firm PBMR (Pty) Ltd. The concept is based not only on helium coolant but also on spherical, rather than prismatic, fuel elements. In 2001, Corbin McNeill, former chief executive officer of Exelon Corporation, proposed that the company might build as many as 40 of the 110-MWe PBMRs. Not long afterward, however, McNeill resigned, and Exelon shelved its plans. Development and promotion continued, but PBMR (Pty) Ltd. was often cash-strapped (as was much of the South African nuclear industry). The U.S. Department of Energy gave some paying work to a PBMR consortium with Westinghouse in 2006 in support of the Next Generation Nuclear Plant (NGNP) project, but a firm offer to build PBMRs never emerged, in South Africa or elsewhere. In 2010, the South African government withdrew its support for the PBMR consortium, and Westinghouse ended its active participation. There has been some involvement of PBMR personnel and inclusion of design aspects in the HTR-PM gas-cooled reactor under construction in China (see page 87).

Despite a Congressional mandate, the **NGNP** mentioned above has been no more developed than the PBMR. Proposed as a very-high-temperature gas-cooled reactor, to be built at Idaho National Laboratory by 2021 and intended to test the practicality and economics of hydrogen production from its nuclear heat, the NGNP is now considered by the DOE to be at most an R&D program. A variety of electricity producers, nuclear industrial firms, and process-heat users have formed the NGNP Industry Alliance, which on its own has chosen AREVA's SC-HTGR (see page 68) as its preferred reactor model and anticipates siting near large chemical plants (perhaps in Louisiana). While the DOE maintains that the NGNP should be a public-private partnership, the agency has not formed such a partnership with the alliance.

A saga nearly as long as the PBMR's is that of Toshiba Corporation's **4S**, which takes its name from the slogan "Super-Safe, Small and Simple." The 4S departs substantially from existing reactor types, with not only sodium coolant and a fast-neutron spectrum, but also a sealed reactor vessel that would be preloaded with enough fuel to last for 30 years (in the 30-MWt version). Once the fuel is exhausted, the entire vessel would then be returned to Toshiba. The 4S for many years had a potential customer, and it was in the United States: the town of Galena, Alaska, which is not on a power grid and provides its electricity from diesel generators. Despite many interactions with the Nuclear Regulatory Commission, which seeks to adhere to a technology-neutral approach to reactor licensing, Toshiba has not made significant headway toward agency approval of 4S. Galena eventually opted for a new conventional power source. Toshiba has continued development work related to the 4S, but it is not currently scheduled to seek NRC certification of the design.

Globally advanced

In 2000, the process of reactor advancement took on a sort of worldwide formality, with the creation of the **Generation IV International Forum (GIF)**, a joint effort among the national governments of a group of countries. The total number has changed frequently, but currently there are 10 active members (Canada, China, Euratom, France, Japan, Russia, South Africa, South Korea, Switzerland, and the United States) and three nonactive members (Argentina, Brazil, and the United Kingdom). The reactor concepts decided on by the participants have not changed since their selection in 2002: gas-cooled fast reactor, lead-cooled fast reactor, molten salt reactor, supercritical water-cooled reactor, sodium-cooled fast reactor, and very-high-temperature reactor.

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Each concept has a subgroup of GIF members exploring it in various ways, generally through simulations or proof-of-concept experiments; none of the six has progressed to the point where someone would develop a full plant design, let alone propose it for construction and operation. A technology roadmap update in January 2014 anticipates that work during the next 10 years will remain in the R&D realm for all six concepts, and that deployment will take place at some unspecified times after 2030.

More recent advanced

It may be in the nature of people who have both the attitude and the aptitude to become nuclear professionals to seek to take the technology further, extract even more of the potential energy, and find new ways to improve the environmental effects. A major difficulty for any such endeavor is that a significant departure must be backed by a vast amount of meaningful data to underscore the technology's safety and practicality. Among the newer organizations that are pursuing technologies outside the current comfort zone for regulators, at least two are seeking to build on concepts that have some (though perhaps not yet enough) data behind them. We are not sure if these companies, both in the United States, really rise above our small-group-without-money cutoff, but we will note briefly **X-Energy**, which is backing a PBMR-based concept and notified the NRC early this year that it would apply for design certification in 2017 (and later became less specific); and **Transatomic Power,** which is pursuing a molten salt reactor similar to that proposed by the Canadian firm Terrestrial Energy (see page 54).

A more established presence in nuclear energy, with a fair amount of fuel-related and consulting business, is **Lightbridge,** which in its own way is seeking to expand the range of nuclear energy without necessarily proposing a specific advanced reactor design. One of its products under development is a thorium-based seed-and-blanket fuel assembly, which could offer an opening into a U-233 fuel cycle.

Every advanced reactor development effort relies on the belief that the core principle behind the effort—that it is worthwhile to extract energy from the fissioning of certain actinide nuclei—will continue to be valid decades from now. It seems likely that at least there would be abundant fuel far into the future (if breeding or other actinide-burning methods mature and become accepted), but the needs of future energy users and the prospects for nonfission sources (fusion and orbital solar, among others) can only be guessed at. There is no reason for the pursuit of new reactor concepts not to continue, because practicality will ultimately winnow the field of contenders to an understandable few—as it has done before, and as it is probably doing now. **NN**