

Too much to ask: why small modular reactors may not be able to solve the problems confronting nuclear power

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NM790.4409 Over the last few years, much hope has been invested in what are called Small Modular Reactors (SMRs) as a possible way to address some of the key problems with existing nuclear reactor designs and fuel cycles and thereby offer a brighter future for nuclear power. Several countries are in the fray to develop SMRs, including the United States, Russia, China, France, Japan, South Korea, India, and Argentina. Several of these countries are providing substantial government support for such reactors. Regulatory agencies in these countries are also in the process of grappling with licensing SMRs, many of which incorporate novel features in their designs. SMR designs typically have power levels between 10 and 300 MWe, much smaller than the 1000–1600 MWe reactor designs that have become standard.

Proponents of SMRs have made extensive claims, directed both at large industrialized countries and developing countries, about the purported benefits of SMRs and their abilities to help meet various social and environmental goals. However, a careful look at the technical characteristics of SMRs suggests SMRs may not be able to solve simultaneously the “four unresolved problems” of costs, safety, waste, and proliferation, identified in a 2003 Massachusetts Institute of Technology study as responsible for the “limited prospects for nuclear power today.” The leading SMR designs under development, it turns out, involve choices and trade-offs between desired features and focusing on any one goal, for example cost reduction, might make other goals more difficult to achieve.

SMR families

To simultaneously deliver lowered costs, increased safety, reduced waste, and enhanced proliferation resistance sets a very high bar for SMRs designs. The question is whether existing SMR designs can realize all of these goals? Answering this question is not straightforward. There are a very wide variety of SMR designs with distinct characteristics that are being developed. These designs vary by power output, physical size, fuel geometry, fuel type and enrichment level (and resulting spent fuel isotopic composition), refueling frequency, site location, and status of development. To make some sense of the different designs, Alexander Glaser of Princeton University has proposed that they be categorized into four families.

The first family of SMRs involves reactor designs intended to “get into the game early” and will likely be the first on the market. These are essentially scaled-down standard light water reactors, usually with steam generators located within the same pressure vessel

as the reactor itself (integral Pressure Water Reactor or iPWR). Integration of the primary system has been assessed by some analysts to be “the biggest challenge to SMR development”. These reactors are typically fueled with low enriched uranium, with enrichment levels of 5% or less. Not only is the enrichment of fuel in the same ballpark as conventional light water reactors, but even the fuel assembly designs are intended to be almost identical to existing designs (although scaled down in height). Because of the similarity of the fuel design, the spent fuel can be reprocessed using traditional and widely understood techniques such as PUREX.

A second family of SMRs involves a design, the high temperature gas-cooled reactor (HTGR), that hopes to “succeed the second time around.” Earlier attempts at commercializing similar designs failed. These reactors typically use uranium enriched to well above 5 percent as fuel, and graphite as a moderator. Helium or carbon dioxide is often used as the coolant fluid. The fuel for these reactors is usually in the form of TRISO (tristructural-isotropic) particles, which consist of uranium coated with multiple layers of different materials that can withstand high temperatures and are hard – but not impossible – to reprocess.

The next category of reactors attempts to “deal with the waste legacy” while extending uranium resources by using uranium much more efficiently. Reactors in this family are based on the use of fast neutrons without any moderator. They may have long-lived cores, designed not to require refueling for two or more decades, and may be helium or sodium-cooled. Their distinguishing feature is their use of spent nuclear fuel or nuclear waste or even weapon-grade plutonium as fuel.

Lastly, there are designs intended as “nuclear batteries”, with long-lived cores that are designed for possibly unattended operation. They are generally targeted at “newcomer” nations with small electric grids interested in developing nuclear power systems or for remote locations in developed countries. These reactors tend to be liquid metal-cooled fast reactors with high enrichment levels required for fresh fuel.

Choices and conflicts

Evaluating all the different SMR designs, even when they are organized in families, against the desired criteria of costs, safety, waste, and proliferation is not straightforward. Each of these criteria has several dimensions, and multiple technical characteristics are needed to effectively implement each criterion.

The economics of nuclear power, for example, is a challenge both because of the high cost of constructing

each facility and the high cost of generating each unit of electrical energy relative to other options for meeting the same demand. The two are related but distinct. Even if SMRs might ameliorate the first challenge to some extent, they might make the latter challenge even harder to meet. Conversely, a large energy project might produce lower cost electricity relative to a small power plant but might have difficulty getting off the ground because of the high initial expenditures.

Proliferation resistance is another characteristic that imposes sometimes contradictory requirements. One way to lower the risk of diversion of fuel from nuclear reactors is to minimize the frequency of refueling because these are the periods when the fuel is out of the reactor and most vulnerable to diversion, and so many SMR designers seek longer periods between refueling. However, in order for the reactor to maintain reactivity for the longer period between refuelings, it would require starting with fresh fuel with higher uranium enrichment or mixing in plutonium. Some designs even call for going to an enrichment level beyond 20 percent uranium-235, the threshold used by the International Atomic Energy for classifying material as being of “direct use” for making a weapon. All else being equal, the use of fuel with higher levels of uranium enrichment or plutonium would be a greater proliferation risk, and is the reason why so much international attention has been given to highly enriched uranium fueled research reactors and converting them to low enriched uranium fuel or shutting them down.

Moreover, an SMR design relying on highly enriched uranium fuel creates new proliferation risks – the need for production of fresh highly enriched uranium and the possibility of diversion at the enrichment plant and during transport. Any reduction of proliferation risk at the reactor site by reducing refueling frequency, it turns out, may be accompanied by an increase in the proliferation risk elsewhere.

Technical characteristics and consequences

The multitude of SMR designs that are being developed make it hard to make general statements with wide applicability about how well SMRs as such could meet the requirements for cost, safety waste and proliferation resistance. At the same time, the different designs do have some shared technical characteristics, and these characteristics affect how these reactors might score on different desirable criteria. The table uses the idea of SMR families to summarize some of the broadly shared technical characteristics and their impacts:

SMR family	Technical characteristic	Cost	Safety	Waste volume	Proliferation risk
iPWR	Smaller size, lower fuel burnup	Higher	Increased	Larger	Increased
HTGR	Lower power density and higher enrichment level	Higher	Increased	Mixed impact	Mixed impact
Fast reactors	Higher power density and higher fissile content, molten metal coolants	Higher	Decreased	Smaller	Increased

The smaller power capacity of SMRs has a largely negative effect on costs. Designers hope that this negative effect possibly could be offset somewhat through economies of mass manufacture or by regulatory authorities relaxing licensing rules. But most experts conclude that it seems unlikely that any such offsets in cost would be sufficient to make these reactors economical.

In addition, there are specific features of each of these SMR types that would tend to increase costs. For example, the lower fuel burnup in iPWRs means that fueling costs would be higher whereas the special materials used to coat the fuel particles in high temperature reactors and non-conventional manufacturing techniques also lead to higher fueling costs.

The small physical size and smaller fissile inventories of SMRs, on the other hand, benefit safety. However, in the case of fast reactors, there are other characteristics that affect safety negatively. These include the potential in the core for accidents involving disassembly and reactivity increase as well as the risks from using molten metals as coolants. Proponents of these reactors argue, not surprisingly, that they are safe, but many others view the use of fast spectrum neutrons and molten metal coolants as a significant disadvantage from a safety perspective.

The use of fast neutrons for these reactors is primarily motivated by waste reduction not safety. Indeed, SMRs based on fast neutrons do produce a lower amount of radioactive waste per unit of electricity generated. The significance of the lower rate of waste generation, however, is debatable. The problem with siting geological repositories for waste disposal has been local and public resistance. The level of resistance is not particularly sensitive to the amount of waste that might be disposed of in the repository. In other words, even if the repository were to be designed to deal with a significantly smaller volume of spent fuel, there may not be a corresponding decrease in opposition to siting the facility.

Proliferation risk, the fourth goal, depends on both technical and non-technical factors. While the non-technical factors are largely not dependent on choice of reactor type, SMRs and their intrinsic features do affect the technical component of proliferation risk. In the case of both iPWRs and fast reactors, the proliferation risk is enhanced relative to current generation light water reactors primarily because greater quantities of plutonium are produced per unit of electricity generated. In the case of HTRs, proliferation risk is increased

because of the use of fuel with higher levels of uranium enrichment, but is diminished because the spent fuel is in a form that is difficult to reprocess.

Conclusion

Proponents of the development and large scale deployment of small modular reactors suggest that this approach to nuclear power technology and fuel cycles can resolve the four key problems facing nuclear power today: costs, safety, waste, and proliferation. Nuclear developers and vendors seek to encode as many if not all of these priorities into the designs of their specific nuclear

reactor. The technical reality, however, is that each of these priorities can drive the requirements on the reactor design in different, sometimes opposing, directions. Of the different major SMR designs under development, it seems none meets all four of these challenges simultaneously. In most, if not all designs, it is likely that addressing one of the four problems will involve choices that make one or more of the other problems worse.

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Standardised reactor designs

In addition to the rhetoric about small modular reactors, the nuclear lobby claims that standardised designs and modular construction are 'game changers' for large reactors. The Vogtle / Georgia and Summer / South Carolina projects in the US provide a test of the rhetoric. These AP1000 reactors are being assembled in large modules.¹

A factory in Louisiana operated by Shaw Modular Solutions constructed prefabricated sections for AP1000 reactors but experienced delays due to quality assurance, design and fabrication problems. Now the firms leading the reactor projects are phasing out the Louisiana factory for work on the biggest modules and contracting with new manufacturers. The Vogtle and Summer AP1000 projects are both behind schedule and over-budget.

Nuclear Regulatory Commission (NRC) officials proposed a US\$36,400 (€27,700) fine against The Shaw Group for firing a quality insurance supervisor who

warned a potentially faulty part may have been shipped to a project in New Mexico. The fine was dropped after the company agreed to changes. The NRC also said that workers at the Louisiana factory feared raising safety and quality concerns to their supervisors. The NRC concluded that a welder at the Louisiana factory took a qualification test for another worker in 2010, and that a supervisor knew but did not report it.

The now-abandoned plan for new reactors at the Temelin plant in the Czech Republic gives another insight into the rhetoric about standardised designs. The Czech government's nuclear envoy Václav Bartuška has provided an insightful post-mortem of the cancelled Temelin expansion project. He notes that Areva, Westinghouse and Rosatom all argued that their offer would be a standardised design, but none of them in fact was. For example, Areva's EPR in China is 450 MWt more powerful than the one in Finland, and Areva confirmed that only 50% of the nuclear island is the same.²

1. 26 July 2014, 'Promises of Easier Nuclear Construction Fall Short'

<http://abcnews.go.com/US/wireStory/promises-easier-nuclear-construction-fall-short-24725848>

2. Jan Haverkamp, 27 Aug 2014, 'Czech nuclear envoy has interesting insights into the problems with nuclear power'

www.greenpeace.org/international/en/news/Blogs/nuclear-reaction/czech-nuclear-envoy-has-interesting-insights-/blog/50403/

– Nuclear Monitor

Chinese inland provinces: Nuclear power at the crossroads

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NM790.4410 In the hope of becoming China's first inland nuclear power project, Pengze Nuclear Power Project (owned by China Power Investment Group) in Jiangxi Province has begun pre-construction work. However, the project has met resistance from the government and residents of the downstream Wangjiang prefecture in neighbouring Anhui Province. The Wangjiang government has publicly accused Pengze Project of falsifying its EIA report. Such confrontation shows Wangjiang's deep concern over the close proximity of a nuclear power plant.

Nuclear power requires large volumes of water for cooling. Adequate water supply is the key factor for identifying potential plant sites. Pengze was chosen due to its proximity to the Taipo Lake and the Yangtze River. However, unlike inland nuclear project areas in the United States, which often have few people downstream, China is relatively densely populated. China's vast river network and dense population distribution mean inland nuclear power stations have many inherent risks.