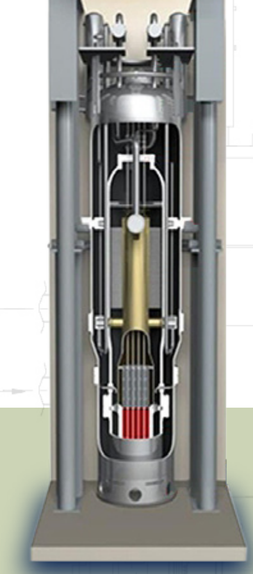
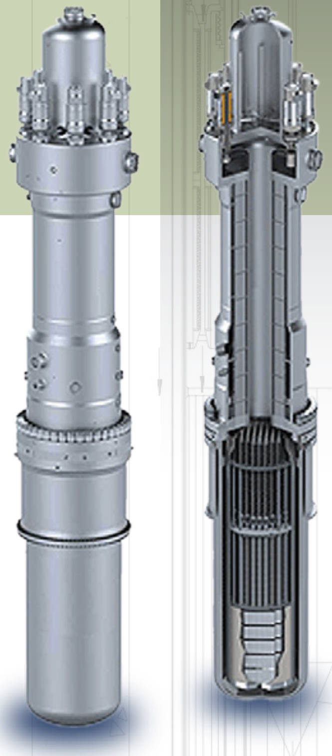


Small Isn’t Always Beautiful

Safety, Security, and Cost Concerns about Small Modular Reactors



Union of Concerned Scientists

Small Isn't Always Beautiful

Safety, Security, and Cost Concerns about Small Modular Reactors

Edwin Lyman

Union of Concerned Scientists

September 2013

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Edwin Lyman is a senior scientist in the Union of Concerned Scientists Global Security Program.

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Acknowledgments

This report was made possible by funding from Park Foundation, Inc., Wallace Research Foundation, an anonymous foundation, and UCS members. The author would like to thank Trudy E. Bell for outstanding editing, Rob Catalano for design and layout, Bryan Wadsworth for overseeing production, and Scott Kemp, Lisbeth Gronlund, and David Wright for useful discussions and comments on the report.

The opinions expressed herein do not necessarily reflect those of the organizations that funded the work or the individuals who reviewed it. The author bears sole responsibility for the report's content.

Executive Summary

Nuclear reactors that are small and modular—reactors that generate up to about a third the power of the typical commercial reactor—have received positive attention in Congress and elsewhere as a possible way of introducing nuclear generating capacity in smaller and more affordable increments.

Advocates assert that cost savings would be realized by mass-producing major components as standard modules in factories, and shipping the modules to sites for assembly rather than having each reactor custom-designed and built. Smaller-sized reactors would also have lower construction costs. Supporters also state that designs for small modular reactors (SMRs) would be inherently safer, so they could be located closer to densely populated areas than large reactors, even replacing coal-fired power plants at existing sites. Proponents even claim that certain safety regulations of the Nuclear Regulatory Commission could be relaxed for SMRs.

Less expensive does not necessarily mean cost-effective, however. The safety of the proposed compact designs is unproven—for instance, most of the designs call for weaker containment structures. And the arguments in favor of lower overall costs for SMRs depend on convincing the Nuclear Regulatory Commission to relax existing safety regulations.

> *The challenge is to reduce cost without compromising safety and security.*

Reactor owners can be tempted to lower costs by cutting corners. The challenge is to reduce cost without compromising safety and security. Given that the Fukushima Daiichi accident review has already resulted in new safety requirements for both operating and new reactors, some of which may be costly, we need research that will show how to lower the cost of nuclear reactor systems while increasing their levels of safety and security. Safety and security improvements are critical if nuclear power is to be a viable energy source for the future.

To this end, Congress should direct the Department of Energy (DOE) to spend taxpayer money only on support of technologies that have the potential to provide significantly greater levels of safety and security than currently operating reactors. The DOE should not be promoting the idea that SMRs do not require 10-mile emergency planning zones—nor should it be encouraging the NRC to weaken its other requirements just to facilitate SMR licensing and deployment.

Introduction and Overview

Will SMRs prove to be both safer and cheaper than larger reactors, as proponents claim?

According to the U.S. Department of Energy (DOE) and some members of the nuclear industry, the next big thing in nuclear energy will be a small thing: the "small modular reactor" (SMR). "Small" is defined by the DOE as one that generates less than 300 MWe (megawatts of electric power), which is about 30 percent of the capacity of a typical current commercial-power reactor. "Modular" refers to the concept that the units would be small enough to be manufactured in factories and shipped to reactor sites as needed to meet incremental increases in demand (Smith-Kevern).

Promoters of SMRs, including the DOE, argue that their smaller size will lower construction costs, thus overcoming one significant barrier to building new reactors (NRC 2011a). They further maintain that cost savings can be achieved through mass production of modular components. One of the chief proponents of SMR technology is Pete Lyons, assistant secretary for nuclear energy at the DOE, who said in June 2013 that, "I think the small modular reactors can truly offer a new paradigm in the way we look at nuclear power in this country. There are many, many safety and security benefits from the small size and new design. From an economic standpoint the cost involved is much, much smaller" (Flessner).

Will SMRs prove to be both safer and cheaper than larger reactors, as proponents claim? Or, as opponents caution, will improved safety come only at the expense of SMRs' economic competitiveness? That is, will they bring to the table just a different set of problems?

SMRs are not a new idea, but interest in them has waxed and waned periodically over the last several decades. Most recently, SMRs are regarded as a way to expand nuclear energy by introducing it into new markets, such as small utilities that cannot afford the huge price tag of conventionally sized nuclear plants, or countries with electric grids that cannot handle the output of large reactors.

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To reduce the risk of events similar to the March 2011 disaster at Japan's Fukushima Daiichi plant, the next generation of nuclear power plants must be far safer than the current generation.

SMRs have attracted strong positive interest in Congress. The DOE is supporting their accelerated development and deployment through its Licensing Technical Support Program. This program is making available $452 million in matching grants over five years to industry applicants to subsidize the costs of designing and licensing SMRs, aimed at "expeditious deployment" of a commercial SMR by 2022.

SMRs receive high praise from some corners of government, industry, and media. However, given the immaturity of the SMR enterprise at this time, this praise borders on irrational exuberance. In fact, the level of optimistic rhetoric has begun to concern even some SMR supporters. John E. Kelly, deputy assistant secretary for nuclear reactor technologies at the DOE, warned industry attendees at a May 2013 SMR conference in Washington, DC, sponsored by Platts of the dangers of overselling the benefits of the technology (Kelly 2013).

SMR advocates assert that small reactors will offer cost and safety benefits over large reactors. Indeed, some SMR designs may offer certain safety advantages over existing reactors because their smaller cores are easier to keep from overheating. However, keeping costs down also may require safety compromises in other areas. In particular, the economic case for SMRs depends in part on the assumption that the Nuclear Regulatory Commission (NRC) can be convinced to grant SMRs regulatory relief in safety and security areas. Thus, whatever intrinsic safety advantages are unique to SMRs could be lost if the NRC allows safety margins to be reduced in other respects. Such an approach would truly be "robbing Peter to pay Paul."

Following the airborne suicide terrorist attacks on the World Trade Center and the Pentagon on September 11, 2001, the NRC required new U.S. reactors to be more secure against aircraft attacks. The agency has otherwise rebuffed calls to require new reactors to be safer than the current generation, however, out of fear that such a requirement would cause the public to question the safety of the operating reactor fleet. Without such a requirement, plants that incorporate additional safety features that increase cost will be at a competitive disadvantage economically to those plants that meet only minimum standards.

Greater levels of nuclear plant safety and security cannot be achieved by smart design alone.

The three reactor meltdowns and release of radioactive material at the Fukushima Daiichi nuclear power plant in Japan after the Great East Japan earthquake and tsunami on March 11, 2011, revealed serious deficiencies in the design, regulation, and operation of the current generation of nuclear power plants. To reduce the risk of similar events at other plants in the future, the next generation of plants must be far safer than the current generation. Some SMR vendors deserve credit for addressing certain severe accident vulnerabilities through the designs of their reactors. However, they do not go far enough.

For any plant, large or small, a key factor that determines the level of safety is the most severe accident that the plant is designed to withstand without exceeding certain radiological release limits—a hypothetical event known as the maximum "design-basis" accident. For current plants, the most challenging design-basis accident is an event far less severe than what occurred at Fukushima. The NRC is currently considering proposals that would expand the range of accidents that plants would be required to be able to withstand. All plants—whether large or small, actively or passively safe—should be prepared to withstand accidents or sabotage attacks resulting in site conditions comparable to what was experienced at Fukushima.

Moreover, greater levels of nuclear plant safety and security cannot be achieved by smart design alone. It must also extend to operation. Without an overarching regulatory framework focused on substantially increasing the level of operational safety, there will be no assurance of greater safety for next-generation reactors either large or small.

Thus, the first step toward increasing the safety level of the next generation of reactors should be the development by the NRC of more stringent safety requirements for all reactors, regardless of size. Small and large reactors alike should compete on a level

"Affordable" doesn't necessarily mean "cost-effective."

playing field. Those SMRs that have safety advantages compared with large reactors should have an easier time meeting any increased safety requirements that are needed after Fukushima.

Yet, far from increasing design and operational safety standards, proponents of SMRs claim small modular reactors will be so much safer than large reactors that they will not need to meet the same safety standards as large reactors, arguing that they need far fewer operators and security officers, and that they can have disproportionately smaller and weaker containment buildings. SMR advocates claim that they are so safe they can be located close to densely populated areas without the need for extensive evacuation planning. This argument is a crucial part of the case being made by the DOE and others that SMRs can be deployed to replace coal plants at existing sites, many of which are near urban areas.

We consider each of those issues below.

Economic Analysis

As natural gas prices have declined and as years of recession and slow recovery have weakened the demand for electricity, the prospects for nuclear power have dimmed in the United States. In such an economic environment, the construction cost of a new conventionally sized light-water reactor has proven to be a formidable obstacle for most utilities, even with the prospect of government-underwritten loan guarantees and other subsidies. The official estimated construction cost for the two new Westinghouse AP1000 pressurized-water reactors (approximately 1,100 MWe each) under construction at the Alvin W. Vogtle Electric Generating Plant near Waynesboro in eastern Georgia is now around $7 billion each.

Promoters of SMRs, including the DOE, point out that by virtue of the plain fact that they are smaller, the capital cost of an SMR will be less than that of a large reactor of the same design because construction will require fewer construction materials, less labor, and less time. Those factors could overcome one significant financing barrier to building large reactors (NRC 2011a). They emphasize that SMRs are thus more "affordable" than large reactors (Ingersoll).

However, "affordable" doesn't necessarily mean "cost-effective." According to basic economic principles, the cost per kilowatt-hour of the electricity produced by a small reactor will be higher than that of a large reactor, all other factors being equal. That is because SMRs are penalized by the economies of scale of larger reactors—a principle that drove the past industry trend to build larger and larger plants (Shropshire). For example, a 1,100 MWe plant would cost only about three times as much to build as a 180 MWe version, but would generate six times the power, so the capital cost per kilowatt would be twice as great for the smaller plant (see, e.g., the economies of scale formula used by Carelli et al.).

SMR proponents argue that other factors could offset this difference, effectively reversing the economies of scale. For example, efficiencies associated with the economics of mass production could lower costs if SMRs are eventually built and sold in large numbers. Such factors are speculative at this point, however, and the degree to which they might reduce costs has not been well characterized. A 2011 study found that even taking into account all the factors that could offset economies of scale, replacement of one 1,340 MWe reactor with four 335 MWe units would still increase the capital cost by 5 percent (Shropshire).

The potential cost benefits of assembly-line module construction relative to custom-built on-site construction may also be overstated. Moreover, mistakes on a production line can lead to generic defects that could propagate through an entire fleet of reactors and be costly to fix. The experience to date with construction of modular parts for the nuclear industry has been troubling. For example, a plant to fabricate modules (built in Lake Charles, Louisiana, by the Shaw Group, later acquired by Chicago Bridge and Iron) for the AP1000s under construction in Georgia and South Carolina has had serious production delays and other problems that have caused slips in the construction schedules and cost escalation for those projects. In April 2013, the NRC subpoenaed documents from Shaw regarding possible falsification of quality assurance documents and cited the company for creating a “chilled work environment” to dissuade workers from raising safety concerns (Freebairn).

Unless the negative economies of scale can be overcome, SMRs could well become affordable luxuries: more utilities may be in a financial position to buy an SMR without “betting the farm,” but still lose money by producing high-cost electricity. In any event, it would take many years of industrial experience, and the production of many units, before the potential for manufacturing cost savings could be demonstrated. In the meantime, as the Secretary of Energy Advisory Board’s SMR subcommittee stated in a November 2012 report, “first of a kind costs in U.S. practice will likely make the early [SMR] units considerably more expensive than alternative sources of power. If the U.S. is to create a potential SMR market for US vendors, it will need to do something to help out with such costs” (SEAB). The report pointed out that if the government decided to provide such help, it would have a “panoply of direct and indirect tools available to support the development of an SMR industry” ranging from “funding SMR demonstration plants, perhaps on U.S. government sites (the DOE is a particularly large user of electricity) to a variety of financial incentives” including “continued cost sharing with selected SMR vendors beyond design certification,” “loan guarantees,” and “production tax credits or feed-in tariffs for those utility generators that are early users of SMR power purchase contracts.” Indeed, only one SMR proposal in the United States was selected by the DOE for its Licensing Technical Support Program: the TVA mPower project at Clinch River, Tennessee; it is the one best positioned to benefit from additional DOE “policy tools”—that is, subsidies—by securing a long-term power purchase agreement with the DOE’s adjacent Oak Ridge National Laboratory.

DOE officials have referred to this situation as a "Catch-22." The economics of mass production of SMRs cannot be proven until hundreds of units have been produced. But that can’t happen unless there are hundreds of orders, and there will be few takers unless the price can be brought down. This is why the industry believes significant government assistance would be needed to get an SMR industry off the ground.

In addition, there appears to be a growing realization that the first SMR production factory cannot fill its order book with domestic units but will need to access a sizable international export market. Edward McGinnis, deputy assistant secretary for international nuclear energy policy and cooperation at the DOE, told the May 2013 Platts SMR vendor conference that, “In my view, much of your order book will come from the Chinese” (McGinnis 2013). McGinnis did not explain why he thought China—one of the world’s leading exporters and a country with low labor and construction costs—would be a viable customer for a large number of U.S. reactors, in light of the fact that China’s nuclear import strategy has been to purchase a small number of foreign units and then reverse-engineer them to develop domestically produced versions. Other countries the DOE identified as potential markets for U.S. SMRs include Bangladesh (a country with a clear need to strengthen occupational health and safety rules), Kenya, Namibia, Nigeria, and Vietnam.

In addition to imposing a penalty on the capital cost of SMRs, economies of scale would also negatively affect operations and maintenance (O&M) costs (excluding costs for nuclear fuel, which scale proportionately with capacity). Labor costs are a significant fraction of nuclear plant O&M costs, and they do not typically scale linearly with the capacity of the plant: after all, a minimum number of personnel are required to maintain safety and security regardless of the size.

For instance, until 2013 there were two operating nuclear plants in Wisconsin—Kewaunee Power Station (owned by Dominion Resources) and Point Beach Nuclear Power Plant (owned by NextEra Energy)—only five miles apart. Kewaunee had a single-unit, 556 MWe reactor and Point Beach has two reactors with a total of 1,023 MWe. Even though Kewaunee generated only half the electricity of Point Beach in 2011, it had 700 employees during operation, or 1.3 workers per MWe whereas Point Beach had 690 employees, or only 0.67 worker per MWe (Mathews). Indeed, the cost of labor at Kewaunee was likely a factor in Dominion’s 2012 decision to shutter the plant this year. In explaining its decision, Dominion cited its inability to achieve “economies of scale” through expanding its nuclear plant holdings in the region “to leverage the megawatts and the shared staff” of multiple plants (Content 2012). In contrast, Southern Nuclear Operating Company estimates that it will need only 800 employees to staff its two new AP1000 reactors—which together will generate over 2,200 MWe—at the Vogtle site, amounting to only

SMR vendors are pressuring the NRC to weaken regulatory requirements for SMRs.

0.36 worker per MWe. Unless utilities can find a way to justify significantly reducing personnel for smaller reactors, SMRs will need a larger number of workers to generate a kilowatt of electricity than large reactors. Yet a 2011 study of 50 small and medium-sized reactors in Europe concluded that O&M costs must be kept consistently "low"—defined as less than 20 percent of total costs—to maintain SMR cost competitiveness (Shropshire).

To reduce both capital costs and O&M costs, SMR vendors are pressuring the NRC to weaken certain regulatory requirements for SMRs. Indeed, the DOE's John Kelly told the NRC in March 2011 that the NRC's regulatory requirements for SMRs will "directly influence the operating cost, which will be a large determinant into the economic feasibility of these plants" (NRC 2011a).

The industry argues that regulatory requirements for SMRs in areas such as emergency planning, control room staffing, and security staffing can be weakened because SMRs contain smaller quantities of radioactive materials than large reactors and can be built underground, therefore posing lower risks to the public (Generation mPower 2013). The NRC is currently considering the technical merits of such arguments.

If the NRC ultimately decides to grant SMRs regulatory exemptions or to revise its rules for SMRs, the risk to the public from accidents (per unit of electricity generated, as opposed to per reactor) may well increase. In contrast, if the NRC maintains that SMRs must meet the same safety requirements as large reactors—by, say, requiring the same number of security staff and size of the Emergency Planning Zones around the reactor—some designs could provide greater safety margins. In any event it would be irresponsible for the NRC to reduce safety and security requirements for any reactor of any size in the post-9/11 and post-Fukushima era.

SMR Designs

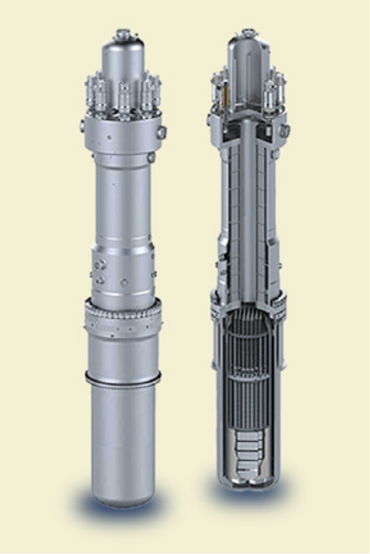
In the past decade around the world, dozens of SMR designs have been proposed. Some use technologies similar to those of current light-water reactors, whereas others are based on new technologies. In the United States, recent attention has focused on designs that have the most in common with the current generation of reactor technology. In particular, the class of SMRs called "integral pressurized water reactors" (iPWRs) is regarded as the least risky with regard to development, licensing, and commercial deployment, even though they still have many unique attributes that will require careful analysis.

The "integral" in iPWR refers to the characteristic that certain systems, structures, and components (SSCs)—notably the steam generators, control rod drive mechanisms, and pressurizer—are integrated into the reactor pressure vessel containing the nuclear fuel. In current-generation large pressurized water reactors (PWRs), such SSCs are external to the pressure vessel. There is no technical reason that would prevent designers from integrating the SSCs into the pressure vessels of large PWRs. However, such hypothetical large integral pressure vessels would not be compatible with factory production because they would be too heavy to transport to reactor sites (using current methods), and therefore would have to be built on site.

The integral design of small iPWRs has advantages and disadvantages. A potential safety benefit is that the design eliminates large-diameter piping outside of the reactor vessel, thus eliminating the possibility of a large-break loss-of-coolant accident from a ruptured pipe. (Such accidents are relatively low-probability events, so the reduction in overall risk may not be very significant.) Of concern, incorporating the steam generators into the same space as the reactor core requires compact and sometimes novel geometries, such as helical coils. That increases the intensity of the radioactive environment in which the generators must operate, and could affect such issues as corrosion and also make the generators much more difficult to inspect and repair. In light of the problems experienced at the San Onofre Nuclear Generating Station in California—shut down for good as a result of the faulty design of new steam generators that led to premature wear—one should not underestimate the potential operating difficulties that could be caused by unexpected problems in novel designs of steam generators and other components. A faulty steam generator in a small, modular iPWR would most likely result in the permanent shutdown of the plant.

The four U.S. iPWR designs that are the most mature are:

Generation mPower. The mPower iPWR, under development by a joint venture of Babcock and Wilcox (B&W) and Bechtel, is a 180 MWe reactor module that would be deployed in groups of either two or four, referred to as "two-packs" or "four-packs." According to the Generation mPower website, the reactor vessel in the current design will be 83 feet high and 13 feet in diameter. However, the website notes that this information is subject to change (Generation mPower 2012). Generation mPower has not made the dimensions of the containment publicly available. The planned generating capacity of each module has increased by nearly 50 percent since the design was initially announced, presumably to improve the economics. The maximum power of 180 MWe is achieved by using a conventional water-cooled condenser servicing the turbine generators; for regions where water is scarce, the company is also offering an air-cooled option that would allow each module to generate 155 MWe. The mPower would normally be cooled by motor-driven pumps; the pumps would be internal to the reactor vessel, but the motors would be external. However, as part of its passive safety features, it also would have an emergency core cooling system that utilizes gravity to pull water into the core. The company states that this system would allow the reactor to cope with a station blackout—that is, a total loss of off-site and on-site electrical power—for 14 days, thereby providing a significant capability to withstand the kind of event that led to the meltdowns at Fukushima Daiichi. Each reactor module would be enclosed in a small steel containment structure and installed underground (Generation mPower 2012).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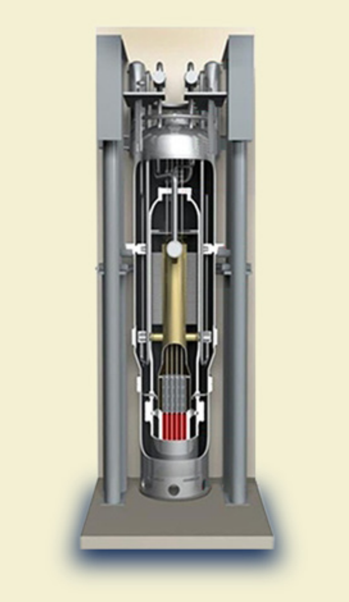
B&W mPower's schedule has slipped, but it currently plans to submit a design certification application to the NRC in the third quarter of 2014. In addition, the Tennessee Valley Authority (TVA) has stated its intention to apply in 2015 for a license to construct up to four mPower modules.[1] In November 2012, the mPower America Team, including B&W mPower, the TVA, and other groups, received the first grant from the DOE under the Licensing Technical Support Program. One of the reasons for the selection was that the DOE believed mPower was the design most likely to achieve NRC certification in the near term, in part because of its similarities to current reactors.

NuScale. The NuScale concept is considerably different from both the mPower SMR design as well as from the current fleet of large nuclear reactors. The NuScale design envisions an array of up to 12 reactor modules, each generating 45 MWe of power, submerged under water in a swimming-pool-like structure. Each module would be 65 feet tall and nine feet in diameter, and would be nested within a very small containment structure 82 feet tall and 15 feet in diameter. Unlike the mPower design, the NuScale control rod drive mechanisms would be external to the vessel. Only natural convection cooling of the core would be used both for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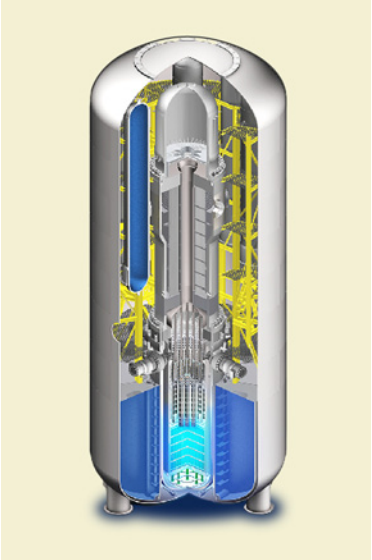
[1] The mPower consortium originally told the NRC that it planned to seek a construction license before it applied for a design certification. The NRC complained in April 2013 that the change in order of the two applications "invalidated" much of the NRC's resource planning for the project.

routine operation and for emergencies: there would be no coolant pumps at all in the primary reactor coolant system (the primary cooling system carries heat from the core to the steam generators). The secondary loop, the system that carries steam from the steam generators to the turbines, would still require motor-driven pumps. NuScale differs from other pressurized water reactors in that the primary coolant is not pumped through the steam generators, but flows around outside of them. The secondary coolant is pumped through the steam generator coils. The designers claim that emergency cooling could be maintained indefinitely in a station blackout by relying on a series of valves that do not require electrical power to open or close and achieve their correct positions (Neve).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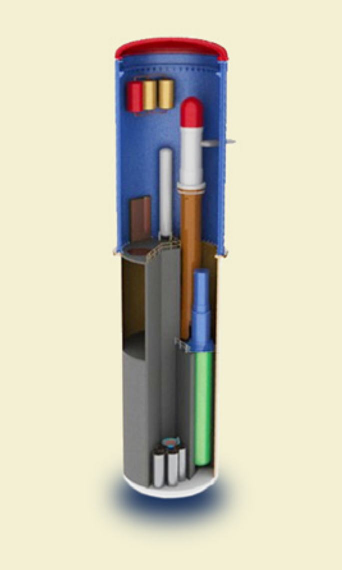
Westinghouse SMR. Westinghouse, after increasing the size of its AP600 passive plant to the AP1000, has now gone in the other direction, designing a 225 MWe version. However, it has disproportionately shrunk the size of the containment structure to a height of 89 feet and a diameter of 32 feet. While the generation capacity of a module would be about a fifth of the AP1000, Westinghouse states that 25 SMR containments—that is, a generating capacity of 5,625 MWe—could fit within the containment of one AP1000 (Shulyak). The design of the Westinghouse SMR has many similarities to the mPower, which has probably hurt its chances of also getting a grant from the DOE Licensing Technical Support Program.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Holtec SMR-160. The Holtec SMR-160 will generate 160 MWe. Like the NuScale, it is designed for passive cooling of the primary system during both normal and accident conditions. However, the modules would be much taller than the NuScale modules and would not be submerged in a pool of water. Each reactor vessel would be located deep underground, with a large inventory of water above it that could be used to provide a passive heat sink for cooling the core in the event of an accident. Each containment building would be surrounded by an additional enclosure for safety, and the space between the two structures would be filled with water. Unlike the other iPWRs, the SMR-160 steam generators are not internal to the reactor vessel. The reactor system is tall and narrow to maximize the rate of natural convective flow, which is low in other passive designs. Holtec has not made precise dimensions available, but the reactor vessel is approximately 100 feet tall, and the aboveground portion of the containment is about 100 feet tall and 50 feet in diameter (Singh 2013).

For these and other SMRs, it is important to note that only limited information is available about the design, as well as about safety and security. A vast amount of information is considered commercially sensitive or security-related and is being withheld from the public. If a particular design is submitted to the NRC for certification or a project is submitted for a combined operating license, more information will become available, although much security-related information and proprietary data will remain inaccessible. As a result, it is not possible at present for external analysts to conduct comprehensive independent reviews of SMR safety and security claims.

SMR Safety

In general, the engineering challenges of ensuring safety in small modular reactors are not qualitatively different from those of large reactors. No matter the size, there must be systems in place to ensure that the heat generated by the reactor core is removed both under normal and accident conditions at a rate sufficient to keep the fuel from overheating, becoming damaged, and releasing radioactivity. The effectiveness of such systems depends on the details of their design. Even nuclear fuel in spent fuel pools, which usually have much lower heat loads than reactor cores, can overheat and rupture if adequate cooling is not provided. For perspective, at Fukushima Daiichi the spent fuel pool at Unit 4 was in danger of overheating even though its heat load was only 2.28 MWth (thermal megawatts); such a heat load is comparable to the decay power of a single NuScale module one hour after shutdown, or a factor of 10 less than the decay power of a 300 MWe reactor a few hours after scram (emergency shutdown).

One attraction of SMRs is their ability to rely on passive natural convection for cooling, without the need for fallible active systems, such as motor-driven pumps, to keep the cores from overheating. The approach is not unique to SMRs: the Westinghouse AP1000 and the GE ESBWR are full-sized reactors with passive safety features.[2] However, it is generally true that passive safety features would be more reliable for smaller cores with lower energy densities.

Certain SMR designs, such as the four iPWRs described above, are small enough that natural convection cooling should be sufficient to maintain the core at a safe temperature in the event of a serious accident like a station blackout. However, some vendors are marketing these designs as "inherently safe," which is a misleading term. While there is no question that natural circulation cooling could be effective under many conditions for such small reactors, it is not the case that these reactors would be inherently safe under all accident conditions. There are accident scenarios in which heat-transfer conditions would be less than ideal and thus natural convection cooling could be impeded. For instance, for the NuScale design a large earthquake could send concrete debris into the pool, obstructing circulation of water or air. Indeed, no credible reactor design is completely passive: no design can shut itself down and cool itself in every circumstance without the need for intervention. Even passively safe reactors require some equipment, such as valves, that are designed to operate automatically. But no valve is 100 percent reliable. In addition, as discussed below, accidents affecting more than one small unit may cause complications that could overwhelm the capacity to cope with multiple failures, outweighing the advantages of having lower heat removal requirements per unit.

The need to reduce SMR capital costs is driving one important passive safety system—the containment structure—to be smaller and less robust.

Ultimately, how well any safety systems work depends on the accidents against which they are designed to protect. Passive systems alone can address only a limited range of scenarios, and may not work as intended in the event of beyond-design-basis accidents. As a result, passive designs should also be equipped with multiple, diverse, and highly reliable active backup cooling systems. Such systems will necessarily be more complex but the engineering challenges should be manageable with good design of instrumentation and control system architecture. Still, more backup systems generally mean higher costs. Thus, a multiple-backup design philosophy is not generally compatible with the small, compact, stripped-down design of the SMRs currently under consideration. Indeed, the passive SMR designs follow the strategy of their large cousins such as the AP1000 in designating all active backup systems as "not safety-related," meaning that they don't have to meet the stringent standards imposed on "safety-related" systems. In addition, designs such as the mPower SMR allow active backup systems to be shared between adjacent units. Sharing saves money, but reduces the likelihood that the active systems will be available during accidents that involve multiple units or go beyond the design basis in other ways.

The need to reduce SMR capital costs is driving one important passive safety system—the containment structure—to be smaller and less robust. None of the iPWR designs has a containment structure around

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[2] The first reactor design with passive safety features to be certified by the NRC was the Westinghouse 600 MWe AP600 in 1998. However, there was no utility interest in the design until Westinghouse uprated it to the larger AP1000 to take advantage of economies of scale.

> *While underground siting would enhance protection against certain events, it could have disadvantages as well.*

the reactor with sufficient strength and volume to withstand the forces generated by overpressurization and hydrogen explosions in severe accidents. SMRs therefore must rely on means to prevent hydrogen from reaching explosive concentrations. However, neither active means (hydrogen igniters) nor passive means (hydrogen recombiners) of hydrogen control are likely to be as reliable as a robust containment. Also, small containment designs will generally result in a greater coupling of the core and the containment, which has potentially negative safety consequences, as became clear after Fukushima Daiichi. The close coupling of the reactor vessel and containment characteristic of its Mark I boiling water reactors resulted in overpressurization of the containments at Units 1, 2, and 3, which made it difficult to inject emergency cooling water into the reactor vessels.

Some SMR vendors propose to locate their reactors underground, which they argue will be a major safety benefit. While underground siting would enhance protection against certain events, such as aircraft attacks and earthquakes, it could have disadvantages as well. Again at Fukushima Daiichi, emergency diesel generators and electrical switchgear were installed below grade to reduce their vulnerability to seismic events, but that location increased their susceptibility to flooding. Moreover, in the event of a serious accident, emergency crews could have greater difficulty accessing underground reactors.

Underground siting of reactors is not a new idea. Decades ago, both Edward Teller and Andrei Sakharov proposed siting reactors deep underground to enhance safety. However, it was recognized early on that building reactors underground increases cost. Numerous studies conducted in the 1970s found construction cost penalties for underground reactor construction ranging from 11 to 60 percent (Myers and Elkins). As a result, the industry lost interest in underground siting. This issue will require considerable analysis to evaluate trade-offs. And if it proves to be advantageous to safety, it remains to be seen whether reactor owners will be willing to pay for the additional cost of underground siting.

Complications of Multiple Reactors at a Site

SMR proponents frequently claim that, like the next generation of large reactors, the probability of reactor core damage can be lower for SMRs than for currently operating reactors. Although true, it is important to note that such claims refer to frequencies of internal events such as pipe breaks. When external events such as earthquakes, floods, and fires are added to a probabilistic risk assessment, however, the Nuclear Energy Institute (NEI)—the policy organization of the nuclear industry—has pointed out that, "the calculated risk metrics for new reactors are likely to increase and therefore be closer to current plants than being portrayed today" (NEI). It should also be noted that the NRC has a long-standing policy that new nuclear reactors, large or small, are not required to be safer than operating reactors, so the current regulatory regime does not mandate that new reactors achieve a substantial decrease in core damage frequency.

SMR proponents also point out that the risk to the public from small reactors is lower than that from large reactors, by virtue of the fact that there is less radioactive material in the core. While that is certainly true, it is not the most useful comparison. The relevant factor with regard to societal risk is not the risk per unit, but the risk per megawatt of electricity generated. By this measure, small reactors do not necessarily imply smaller risks if there are more of them.

To see why, consider the impact on risk if one large unit is replaced with multiple smaller units providing the same total power. If the probability of core damage is comparable for small reactors and large reactors, then the total site risk—the probability of an accident multiplied by its consequence—will also be comparable in both cases (see Figure 1). Indeed, the overall site risk for the multiple SMRs could actually be higher than for a single reactor. The scenario in Figure 1 assumes the damage probabilities and the consequences for the multiple reactors are independent. But they will not be independent unless the potential for common-mode failures and interactions between the multiple reactors are fully addressed.

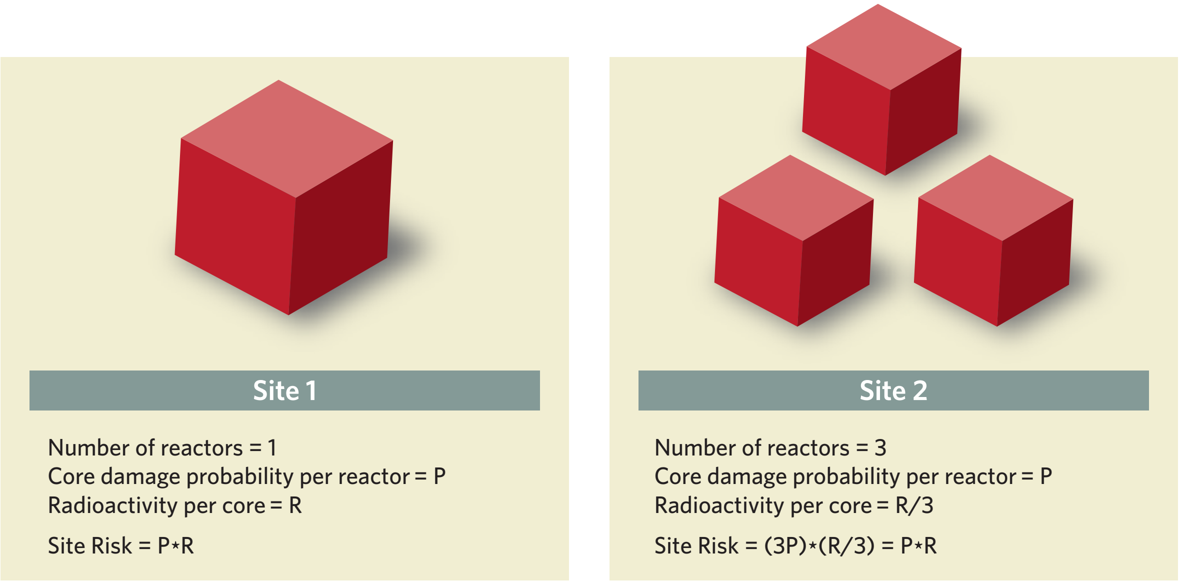
In order for individual reactor units to remain independent, the number of support staff and amount of safety equipment would need to increase with the number of units on a site. Only through significant sharing of systems and personnel by multiple units, however, could the associated cost increase be moderated. Thus, the SMR vendors want to reduce the number of control rooms and licensed operators that the NRC would ordinarily require for a certain number of units. For example, the NuScale design could have a single control room operator in charge of as many as 12 units, the feasibility of which would have to be verified through performance testing.

But such a strategy of sharing would run counter to the lessons of Fukushima. Fukushima demonstrated that multiple-reactor plants that experience severe conditions present extreme challenges. The tsunami affected all the reactors at the site. Emergency personnel and equipment at the plant had to be dispersed to respond to multiple reactors, and were not sufficient. The proximity of neighboring reactors affected the ability of personnel to carry out emergency operations on each reactor, as explosions at one unit disrupted emergency operations at neighboring units.

> *Fukushima demonstrated that multiple-reactor plants that experience severe conditions present extreme challenges.*

Some of the NRC's current regulations and procedures do not account for events affecting multiple reactors at a site. For example, NRC emergency planning regulations focus on single-reactor events in determining requirements for emergency operations staffing, facilities, and computer modeling of radiation releases to help direct evacuations. In addition, the NRC's guidance for probabilistic risk assessment, an analysis tool used in many regulatory applications, does not require the consideration of multiple-reactor events. The NRC is undertaking a research project to conduct a risk assessment for the Vogtle plant that will consider two-unit accidents, but that research is expected to take years. The complexity of an analysis that involves a greater number of units would require an even greater effort.

Figure 1. Comparison of Site Risks for a Single Reactor Unit and Multiple Units with the Same Total Generating Capacity



Site 1

Number of reactors = 1
Core damage probability per reactor = P
Radioactivity per core = R

Site Risk = P*R

Site 2

Number of reactors = 3
Core damage probability per reactor = P
Radioactivity per core = R/3

Site Risk = (3P)*(R/3) = P*R

SMR vendors are vigorously seeking regulatory relief from the NRC that would allow them to meet weaker safety and security standards.

The NRC Fukushima Near-Term Task Force recommended in 2011 that emergency preparedness requirements be revised to address multi-reactor events, which could have a significant impact on SMR licensing (NRC 2011c). The NRC is currently revising certain requirements in response to the Task Force recommendations, but it is not yet clear to what extent its concerns will be addressed. The NRC will also need to fully consider these issues in the context of developing its licensing approach for SMR sites, which may host two to four times the number of units present at the largest U.S. nuclear plant site today, in much closer proximity to one another, and with greater numbers of shared systems. Requiring sufficient equipment and resources at the site to ensure that all the reactors could be safely shut down and managed in an emergency would likely drive up costs. The NRC should ensure these regulatory changes are fully implemented before it begins licensing SMR sites.

Distribution of SMRs

Some SMR proponents argue that the size and safety of the designs of small modular reactors make them well suited for deployment to remote areas, military bases, and countries in the developing world that have small electric grids, relatively low electric demand, and no nuclear experience or emergency planning infrastructure. Such deployments, however, would raise additional safety, security, and proliferation concerns.

First, building many small reactors at a large number of geographically dispersed sites would put great strains on resources for licensing and for safety and security inspections. Even within the United States, the number of resident NRC inspectors would have to increase to accommodate a larger number of units at more nuclear plant sites.

Second, deployment of individual small reactors at widely distributed sites around the world could strain the resources of the International Atomic Energy Agency (IAEA) because inspectors would need to visit more locations per installed megawatt around the world. That strain could degrade the IAEA's ability to safeguard reactors against their misuse for covert nuclear weapon programs. Maintaining robust oversight over vast networks of SMRs around the world would not only be difficult, but also would require the international community to increase funding significantly for the IAEA—a task that has already been extremely difficult to achieve in recent decades.

Third, it is unrealistic to assume that SMRs—especially in the near term—will be so safe that they can be shipped around the world without the need to ensure the highest levels of competence and integrity of local regulatory authorities, plant operators, emergency planning organizations, and security forces. Indeed, many nations where the DOE hopes to export SMRs may not have the resources to safely operate nuclear power plants. For that reason, SMRs should be built only in countries where there is a credible and independent regulatory authority, an established infrastructure to cope with emergencies, and a sufficient number of trained operator and security staff. Fukushima furthermore demonstrated the importance of timely offsite response in the event of a severe accident; thus, the accessibility of reactors in remote locations also must be a prime consideration. Even within the United States, small utilities with little or no experience in operating nuclear plants need to fully appreciate the unique challenges and responsibilities associated with nuclear power and should not expect that small modular reactors will provide relief in this regard.

In 2011, the IAEA specified milestones for evaluating the readiness of nations to initiate nuclear power programs. One major milestone absent from the evaluation, however, is institution of a fully independent, honest and credible nuclear regulator. Given the fact that the lack of an independent nuclear regulator in Japan has been cited as a root cause for the failure of the design, siting, and safety regime that made the Fukushima Daiichi accident possible, the absence of such an explicit milestone is a major oversight on the part of the IAEA.

Regulatory Rollbacks

The SMR vendors are vigorously seeking regulatory relief from the NRC that would allow them to meet

Nuclear reactors, like all elements of critical infrastructure, must be prepared to withstand terrorist attacks.

weaker safety and security standards. Such relief would not necessarily involve actual changes to the NRC's regulations, but could be achieved through a variety of other mechanisms within the existing regulatory framework.

Security of SMRs

The pressure cooker bombs that exploded at the Boston Marathon on April 15, 2013, were a stark reminder of the ongoing terrorist threat in the United States. Nuclear reactors, like all elements of critical infrastructure, must be prepared to withstand terrorist attacks. Fukushima Daiichi demonstrated how rapidly a nuclear reactor accident can progress to a core meltdown if multiple safety systems are disabled. A well-planned and -executed terrorist attack could cause damage comparable to or even worse than the earthquake and tsunami that initiated the Fukushima crisis, potentially in even less time. For these reasons, the NRC requires nuclear plant owners to implement robust security programs to protect their plants against sabotage.

Despite these concerns, SMR proponents argue for reducing security requirements—in particular, security staffing—to reduce the cost of electricity produced by small modular reactors. In 2011, Christofer Mowry, president of Babcock & Wilcox mPower, Inc., said, "Whether SMRs get deployed in large numbers or not is going to come down to O&M [operations and maintenance]. And the biggest variable that we can attack directly, the single biggest one, is the security issue" (NRC 2011a). His position was echoed by the NEI, which submitted a position paper to the NRC in July 2012 on the issue of physical security for SMRs (NEI 2012). It clearly laid out the industry view:

> *The regulatory issue of primary importance related to physical security of SMRs is security staffing. The issue has the potential to adversely affect the viability of SMR development in the U.S. Security staffing directly impacts annual operations and maintenance (O&M) costs and as such constitutes a significant financial burden over the life of the facility. . . . For this reason, evaluation of security staffing requirements for SMRs has become a key focal point.*

The paper goes on to say:

> *[NRC security] requirements, many of which are based on years of operating experience with large LWR [light-water reactor] facilities, may not be appropriate or necessary for SMRs due to the[ir] simpler, safer and more automated design characteristics . . .*

The NRC requires that nuclear power reactors protect against the design-basis threat (DBT) of radiological sabotage. That requirement mandates that armed response forces be deployed round-the-clock at reactors, charged with the sole responsibility for preventing a group of attackers with paramilitary training and weapons from destroying enough plant equipment to result in damage to the reactor core or spent fuel. Before 9/11, the NRC nominally required that 10 armed responders be deployed per shift, but it permitted reactor owners to decrease the number to as few as five if they could justify the reduction. After 9/11, the NRC made the DBT requirement more challenging to reflect the changed threat environment, including increasing the number of assumed attackers and augmenting their capabilities and tactics. The minimum number of armed responders required per shift increased from five to 10. One may thus assume that the average number of armed responders at each site was increased. There are three other required security positions within the protected area: a shift supervisor and officers to operate the central alarm station (CAS) and secondary alarm station (SAS). In addition to the armed responders, additional armed security officers are needed to fulfill other responsibilities, such as securing entry points for personnel and vehicles, and patrolling areas of the plant outside the critical high-security "protected area" fence surrounding the vital areas of the reactor where the armed responders are deployed.

The nuclear industry's preoccupation with reducing security staffing is somewhat surprising. Even though security labor costs are significant, they are far from being a dominant contributor to overall O&M costs. Security staffing costs range from 15 to 25 percent of total O&M costs.

Reducing the security force at nuclear reactors would appear to be penny-wise but pound-foolish.

In total, considering the number of shifts per week, a typical reactor site would need approximately 120 security officers.[3] For comparison, typical total plant staffing is between 400 and 700 personnel per site, so the security force is roughly 20 to 30 percent of the total workforce. B&W mPower estimates an average labor cost of about $120,000 per worker, so a security force of 120 would cost less than $15 million, compared with other labor costs of $35 million to $70 million and the fuel cost of $30 million per year. Yet, the purpose of the security force is to protect the entire plant, personnel, and surrounding region. Reducing the security force would appear to be penny-wise but pound-foolish.

The NRC's radiological sabotage regulations are fairly stringent, but they contain some huge escape clauses. A power reactor applicant that prefers not to comply with a particular requirement has a number of options available. It can propose "alternative measures" provided it can convince the NRC with a technical analysis that the alternatives provide a level of protection that is at least equal to the requirement it wishes to replace. It can propose "license conditions" that would address specific, unique characteristics of a new SMR design. And if all else fails, it can request an exemption from the regulations, which the NRC has broad authority to grant. Because of the flexibility inherent in the regulations, the NRC staff has concluded that "the current security regulatory framework" is adequate to support the licensing of iPWR SMRs and associated activities and is probably adequate for non-light-water-reactor SMR designs as well.

In a presentation to the January 2013 NEI Nuclear Fuel Supply Forum, a Generation mPower representative stated that the current estimate of optimized operating costs for a two-unit, 360 MWe "twin pack" assumed an "80-percent reduction in security staff with normal DBTs" (Generation mPower 2013). In a presentation in May 2013 at the Platts small modular reactor conference, a representative of mPower mentioned a 70 percent reduction (Halfinger 2013). It is hard to see how a 70 or 80 percent reduction in security staff could be achieved without reducing the number of armed responders to well below the minimum number of 10. And if such a great reduction were proportionate across the entire security force, it would reduce the number to only a few armed responders per shift—a number perhaps smaller even than the potential number of armed attackers.[4] Given that the armed attacking force is assumed to be capable of operating in multiple groups, one wonders how such a small number of responders could possibly defend the entire perimeter of the protected area of even a small SMR plant. Because the details of the analysis are not public, however, it is not clear whether mPower would claim such a deep reduction as an alternative security measure or as an exemption. Nevertheless, one thing is clear: a well-planned terrorist attack could indeed cause the kind of large-break loss-of-coolant event that the plant's designers say could not occur in a mere accident. If terrorists were able to access the reactor vessel—a feat more likely with reduced security staffing—they could blow a hole in it in short order, utilizing the explosives that are assumed to be within the design-basis threat.

The NRC staff appears to be open to suggestions for alternative measures that take into account design features of SMRs that may make them less vulnerable to attack. The primary feature that mPower and other SMR vendors appear to credit in seeking relief from security regulations is underground siting. Underground siting would enhance protection against some attack scenarios, but not all. A direct jet impact on the reactor containment is less likely for an underground reactor, but the ensuing explosions and fire could cause a crisis. Certain systems, such as steam

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[3] In 2004, the Nuclear Energy Institute announced that the industry nationwide was in compliance with the NRC's post-9/11 DBT order and had increased the number of its "paramilitary" security forces by 60 percent, to a total of 8,000 officers, or about 120 per site on average. This number appears to include both armed responders and armed security officers. In 2012, the Congressional Research Service reported that, according to the industry, there were about 75 armed responders per plant site (Holt and Andrews 2012).

[4] It is publicly known that the number of attackers assumed in the pre-9/11 design-basis threat was three. The current number is not public, but it is certainly greater than the old number. *Time* reported in 2005 that it is "less than twice" the old number (Lyman).

A well-planned terrorist attack could cause the kind of large-break loss-of-coolant event the plant's designers say could not occur in a mere accident.

turbines, condensers, electrical switchyards, and cooling towers, will need to remain aboveground, where they will be vulnerable. Plants will require adequate access and egress for both routine and emergency personnel. Ventilation shafts and portals for equipment access also provide potential means of entry for intruders. In addition, if SMR sites have smaller footprints, as vendors are claiming, the site boundary will be closer to the reactor, and thus there will be less warning time in the event of an intrusion and potentially insufficient spatial separation of redundant and diverse safety systems.

In short, knowledgeable and determined adversaries will likely be able to develop attack scenarios that could circumvent measures such as underground siting. In situations such as hostage scenarios, terrorists may even be able to utilize the additional defense afforded by an underground site against off-site police and emergency response. Thus, a robust and flexible operational security response will be required no matter what intrinsic safeguards are added to reactor design.

The post-9/11 revision of the NRC's security regulations at power reactors includes an explicit requirement that the NRC conduct periodic performance tests of the armed response strategy. Regulators have come to realize that performance tests are an essential element in assessing the effectiveness of security plans. The NRC utilizes a "composite adversary force" to act as mock attackers during performance tests. Thus, any applicant seeking alternatives to the NRC's security requirements must demonstrate, through rigorous force-on-force performance testing, that its proposed alternative can provide the same level of protection against the DBT.

To this end, it is troubling that the industry appears to be contemplating requesting alternatives to the NRC's requirements for security performance assessments. The NEI's 2012 position paper states:

> *Development of realistic, performance-based security planning appears to be the path offering the most potential in terms of security staff reductions for SMRs. Such planning should recognize and support the use of plant design features and concepts which lessen dependence on security staff interdiction. Successful outcomes of such design features may require development and use of alternative performance assessment techniques.*

The NEI does not explain what it means by "alternative performance assessment techniques." However, it sounds as though the NEI wants to not only reduce security forces for SMRs, but also change the way security is assessed, perhaps even doing away with force-on-force performance testing. That would suggest that the NEI does not have confidence that the industry's approach would be able to pass the NRC's tests that have become the gold standard for security response evaluation.

Whatever is the case, security regulations should not be weakened generically for SMRs. Moreover, design-specific alternatives must meet a very high standard for assurance, including verification through performance testing. As long as domestic terrorist threats continue to persist, it is simply wrong to consider reducing security requirements for nuclear power plants, regardless of their size.

Emergency Planning

Current NRC emergency planning rules require that evacuation plans be developed for people close enough to a nuclear power reactor to be exposed to a plume of radioactive materials in the event of an accident. That translates to a radius of about 10 miles for a reactor having a capacity greater than 250 MWth—corresponding to about 80 MWe for a conventional light-water reactor, or less than a quarter the electric power of an average SMR. The 10-mile evacuation zone is called the inhalation emergency planning zone, or EPZ. The NRC also will provide potassium iodide, which can prevent excessive radiation exposure to the thyroid, free of charge to states

> *SMRs are likely to have challenges keeping electricity costs low enough to be economically competitive with other sources, including larger reactors.*

that request it, but only enough for the population within 10 miles of a nuclear plant. SMR proponents argue that SMRs need not satisfy these requirements because they are safer and smaller than current reactors. In 2011, the NRC staff agreed in principle that the 10-mile EPZ for SMRs could be scaled down—even for units greater than 250 MWth—if an applicant can show that certain dose limits would not be exceeded outside the smaller boundary (NRC 2011b). Those dose limits are related to numeric guidelines in the Protective Action Guides (PAGs) established by the Environmental Protection Agency (EPA). (The NRC did not base its original 10-mile zone determination on the EPA's PAGs.)

SMR vendors and the DOE have used the potential to shrink the radius of the EPZ as a major selling point for SMRs, in order to achieve the greatest possible flexibility in siting. If the radius of EPZs were reduced, proponents assert that SMRs could be located at former coal plants, at industrial sites to provide process heat, at military bases, or indeed in any densely populated area, without the burden of developing evacuation plans and evacuation time estimates, deploying and maintaining sirens, and, most notably, without notifying and educating the public about the need to evacuate. For example, Generation mPower states that it can reduce the EPZ radius for its 360 MWe "two-pack" down to a mere 1,000 feet (Generation mPower 2013)—a distance that could be inside the power plant site boundary! It has not explained the basis for this reduction. Such a small radius would mean that no emergency planning at all would be necessary for the general public. And in its March 2013 second solicitation for its SMR licensing support program, the DOE states that it is looking for designs that "present a credible case to the… NRC to reduce emergency preparedness zone requirements."

The Fukushima Daiichi disaster, however, demonstrated that even a 10-mile-radius zone is inadequate in the case of a severe accident at a conventionally sized reactor, since according to the dose levels specified by the EPA PAGs, evacuation was warranted well beyond that distance. Radiation levels high enough to trigger evacuation were detected at least 20 miles away and those high enough to trigger long-term resettlement were detected more than 30 miles from the Fukushima site. The NRC's dose projections during the early days of the accident indicated that the PAGs could be exceeded even further away, leading it to recommend evacuation of all U.S. citizens as far as 50 miles from the plant. (Fortunately, the accident did not turn out to be as severe as those projections had assumed.) If the appropriate evacuation zone size for a large reactor based on the EPA PAGs is substantially greater than 10 miles it will be unlikely that the appropriate size for a typical SMR would be smaller than 10 miles.

The case for reducing EPZ sizes for SMRs will also depend on the potential redefinition of the NRC "source term"—that is, the postulated release of radioactivity for both design-basis and beyond-design-basis accident scenarios. In order to justify a smaller EPZ size, SMR applicants are not planning to use the one-size-fits-all theoretical source term currently specified in the NRC's regulations. Instead, they intend to calculate the potential radiation exposure to the public based on a source term derived from detailed accident analysis, known as a "mechanistic source term." However, that is likely to be a difficult task. Many questions would first have to be decided. For instance, for a multiple-unit site, would the source term be based only on a single-unit accident? The appropriateness of using only a single unit would depend on whether applicants could demonstrate that the individual units were sufficiently independent of each other. If multiple units were assumed to be involved—as Fukushima revealed, an entirely plausible possibility—any advantage an SMR unit may have by virtue of its smaller size could be erased.

In addition, the calculations used to determine mechanistic source terms would be highly uncertain because SMR reactors themselves are still only paper designs and the codes and models have not been validated with operating experience. State-of-the-art modeling codes cannot even explain many of the features of

> *The soundest way for the United States to maintain a competitive edge in SMRs is to establish American brands with the highest safety standards.*

the Fukushima accident, although the Fukushima Daiichi reactors—all designed and installed by General Electric between 1970 and 1979—were among the longest-operated, best-understood reactor types. Many phenomena that could reduce radiation releases that SMR vendors would like to take credit for, such as retention of radionuclides by the large pool of water in which the NuScale reactor modules would be submerged, or increased radionuclide deposition in a smaller containment, would need experimental validation.

In short, the SMR vendors will have a lot of work to do to support their claims that evacuation planning requirements can be reduced. They should also realize that by going to a mechanistic source term approach they may well be opening a Pandora's box that may affect the EPZs for operating large reactors. The 10-mile EPZ was not tied to a particular dose limit. However, given the observed radiological contamination resulting from Fukushima, it is likely that a technically sound, consistent, dose-based methodology for determining emergency planning requirements would indicate the need for far greater evacuation zone sizes than 10 miles for both large and small reactors. Unless the SMR applicants are able to persuade the NRC that their designs can retain a significantly higher fraction of the radionuclides released from damaged fuel in an accident than large reactors can, the SMR vendors may well be better off sticking to the current 10-mile requirement.

Conclusions

Unless a number of optimistic assumptions are realized, SMRs are not likely to be a viable solution to the economic and safety problems faced by nuclear power.

Indeed, SMRs are likely to have challenges keeping electricity costs low enough to be economically competitive with other sources, including larger reactors. As a result, concerns about costs and competitiveness may drive companies to make decisions about the design and operation of SMRs that undermine any new, inherent safety features not present in current large reactors. For example, designers may reduce other safety features, such as reducing containment strength or the diversity and redundancy of safety systems. Or the NRC may allow SMR owners to reduce the sizes of emergency planning zones and the numbers of operators and security officers per reactor.

Some SMR proponents are concerned that the United States is lagging in the creation of an SMR export market and may lose out if it takes too long to develop and license SMRs. An accident involving a U.S. SMR export, however, would obviously affect the commercial viability not only of the specific brand but also possibly of all small modular reactors and perhaps even of nuclear power in general. Thus, the soundest way for the United States to maintain a competitive edge is to establish American brands with the highest safety standards and ensure that the recipients are capable of operating the plants safely.

Ultimately, the level of safety and security provided by SMRs will depend on the NRC developing and enforcing a strong regulatory framework. Reactor owners can be tempted to lower costs by cutting corners. The challenge is to reduce cost without compromising safety and security. Given that the Fukushima accident review has already resulted in new safety requirements for both operating and new reactors, some of which may be costly, we need research that will show how to lower the cost of nuclear reactor systems while increasing their levels of safety and security. Safety and security improvements are critical to establishing the viability of nuclear power as an energy source for the future.

To this end, the nuclear industry and the DOE should work together to focus on developing safer nuclear plant designs. Congress should direct the DOE to spend taxpayer money only on support of technologies that have the potential to provide significantly greater levels of safety and security than currently operating reactors. The DOE should not be promoting the idea that SMRs do not require 10-mile emergency planning zones—nor should it be encouraging the NRC to weaken its other requirements just to facilitate SMR licensing and deployment.

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Small Isn't Always Beautiful

Safety, Security, and Cost Concerns about Small Modular Reactors

Small modular nuclear reactors (SMRs)—reactors that generate up to about a third the power of the typical commercial reactor—have received positive attention in Congress and elsewhere as a possible way of introducing nuclear generating capacity in smaller and more affordable increments. Advocates assert that SMRs would cost less and be inherently safer than large reactors, so they could be located closer to densely populated areas, even replacing coal-fired power plants at existing sites.

Less expensive does not necessarily mean cost-effective, however. The safety of the proposed compact designs is unproven and the arguments in favor of lower overall costs depend on convincing the Nuclear Regulatory Commission to relax existing safety regulations.

Reactor owners can be tempted to lower costs by cutting corners. We need research that will show how to lower the cost of nuclear reactor systems while increasing their levels of safety and security. Safety and security improvements are critical if nuclear power is to be a viable energy source for the future.

The Union of Concerned Scientists puts rigorous, independent science to work to solve our planet's most pressing problems. Joining with citizens across the country, we combine technical analysis and effective advocacy to create innovative, practical solutions for a healthy, safe, and sustainable future.

This report is available online (in PDF format) at *www.ucsusa.org/SMR*.

National Headquarters
Two Brattle Square
Cambridge, MA 02138-3780
Phone: (617) 547-5552
Fax: (617) 864-9405

West Coast Office
2397 Shattuck Ave., Ste. 203
Berkeley, CA 94704-1567
Phone: (510) 843-1872
Fax: (510) 843-3785

Washington, DC, Office
1825 K St. NW, Ste. 800
Washington, DC 20006-1232
Phone: (202) 223-6133
Fax: (202) 223-6162

Midwest Office
One N. LaSalle St., Ste. 1904
Chicago, IL 60602-4064
Phone: (312) 578-1750
Fax: (312) 578-1751

Web: www.ucsusa.org

Email: ucs@ucsusa.org

Union of Concerned Scientists

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