SMALL NUCLEAR REACTORS

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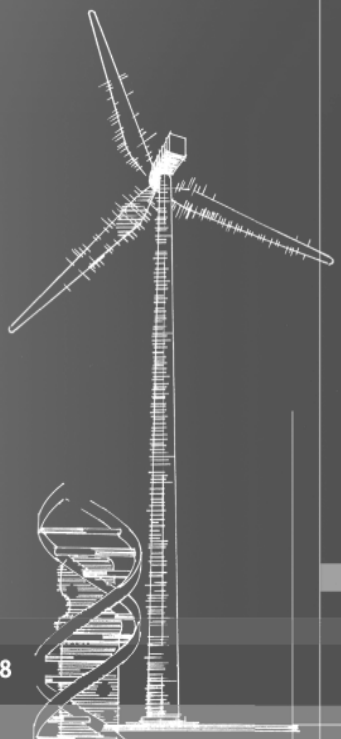
White Paper



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Small Nuclear Reactors[1]

Small nuclear reactors are not currently commercially available, but they present a potential future energy generation technology that offers constant baseload power with no greenhouse gas emissions. Small nuclear power reactors range in size from 10-300 MW, compared to traditional nuclear reactors that are greater than 1000 MW. Over fifty small nuclear reactor designs are in development by universities, national laboratories, and private companies around the world. They are based on a diverse set of technologies including traditional light water reactors, as well as newer gas, liquid metal, and molten salt cooled technologies[2]. Potential applications include:

- Providing power in remote areas, where the cost of building transmission lines is high
- Providing power in developing countries, where smaller transmission systems can't handle large reactors or the capital cost of large reactors is too high
- Powering energy-intensive industrial users, like mining or oil and gas, that need a constant supply of on-site power
- Providing a grid-independent source of power to military bases, to reduce vulnerability to grid disruption
- Providing power for smaller grids (municipal utilities, small cities)
- Providing incremental power expansion for large utilities

Small nuclear reactors were originally developed for defense applications. The US Navy began developing small nuclear reactors for naval propulsion in the early 1950s, and today operates more than 100 reactors aboard aircraft carriers, other surface ships, and submarines. The Army Nuclear Power Program ran between 1954 and 1976, with 8 small reactors constructed to power remote operations. The program was discontinued due to the poor economics of nuclear plants relative to cheaper alternative fuels available at the time.[3] Today, the Army is studying small transportable reactor concepts for power, water, and synfuel production[4,5] and the use of mobile nuclear reactors has been suggested for expeditionary forces.[6] The Air Force explored nuclear powered aircraft, but discontinued the program in 1961. Today, they are considering fielding small nuclear reactors on domestic bases. In January 2008 the Air Force issued a request for proposals, looking for a private company that would be interested in building small nuclear reactors on Air Force bases. However, Air Force spokeswoman Vicki Stein says the Air Force is 12 to 14 years away from building such a power plant.[7]

Modern small reactors are easier to construct and transport than traditional large reactors due to their smaller size. They are safer because they contain less fuel, eliminate design features with higher accident potential, and have passive cooling designs that continue to operate without electrical power, reducing risk of a severe accident. Their smaller size provides more operational flexibility, including increased siting options; an output better matched to load demand and growth; and decreased water use. Economically, they require a much smaller capital investment than large nuclear plants while still providing power at a competitive rate.[8] Nuclear reactors emit no greenhouse gases, providing an emission-free alternative to fossil plants amid increasing concerns about climate change.

Despite these benefits, small reactors have many challenges to overcome. A few designs are in the engineering phase and could be commercialized within a decade, but most designs are still in the research stage, and will require extensive engineering and demonstration before they are ready to be commercialized. The unique design features

[1] This white paper is a literature search on small nuclear reactors. It is not an NREL position.
[2] World Nuclear Association. Small Nuclear Power Reactors. http://www.world-nuclear.org/info/inf33.html
[3] Ingersoll, D. Deliberately small reactors and the second nuclear era. In *Progress in Nuclear Energy 51* (2009) 589-603.
[4] Roege, P. Presentation at theThorium Energy Alliance Conference, October 19, 2009. http://thisweekinnuclear.com/wp-content/uploads/2009/11/05_Roege_DoDnuclear.pdf
[5] Pfeffer, R.; Macon, W. Nuclear Power: An Option for the Army's Future. In *Army Logistician*, Sept-Oct 2001. http://www.almc.army.mil/alog/issues/SepOct01/MS684.htm
[6] Schaeffer, M.; Chang, I. Mobile Nuclear Power for Future Land Combat. Joint Force Quarterly, Issue 52, 1st quarter 2009. http://www.ndu.edu/inss/Press/jfq_pages/editions/i52/11.pdf
[7] Associated Press. Air Force secretary says Cannon being considered nuclear reactor site. The Associated Press State & Local Wire, March 10, 2008
[8] Ingersoll, D.

that make small reactors appealing, like passive safety systems and integral designs, require non-traditional components that will need to be fully developed, tested, and demonstrated. Additional developments in instrumentation and control will be needed for most small reactor designs. Designs that depart from the traditional light water reactor technology may required significant material and fuel qualification as well, which could take 10-12 years or more.[9]

Additional concerns for small nuclear reactors include maintaining the security of many distributed nuclear facilities, controlling nuclear proliferation, and storing radioactive wastes. Small reactors contain smaller amounts of fuel than large reactors, which should make them less appealing targets for sabotage or diversion. To provide additional security, some units are designed to be buried underground. Many small reactors are also designed to be portable (as small as 1.5 meters x 2 meters) and operate for long periods (5-30 years) without refueling. This allows units to be sealed in the factory, shipped to the site via truck or rail, and then returned to the manufacturer for refueling and storage of spent fuel. While these measures provide some increased security and protection against proliferation, more attention to these issues is required.

The increased interest in small reactors is evident in recent policy initiatives. The National Defense Authorization Act for Fiscal Year 2010 includes a provision that requires the Secretary of Defense to conduct a study to assess the feasibility of developing nuclear power plants on military installations by June 1, 2010. The Nuclear Energy Research Initiative Improvement Act of 2009 would require the U.S. Department of Energy (DOE) to "conduct research to lower the cost of nuclear reactor systems." The Nuclear Power 2021 Act requires the DOE to cooperate with two small modular reactor vendors to obtain design certifications from the NRC by January 1, 2018, and to obtain two NRC combined licenses--one for each certified design--by January 1, 2021.[10]

The Department of Energy (DOE) investigated several small reactor designs under its Nuclear Energy Research Initiative. The International Reactor Innovative and Secure (IRIS) design was initiated as a DOE-sponsored research project, and has now evolved into a consortium of over 20 organizations from 10 countries including suppliers, national laboratories, and universities.[11] The NuScale design started as a collaboration between Idaho National Engineering Laboratory and Oregon State University, and was later licensed to NuScale Power Inc. for commercialization. The Hyperion design was developed by Los Alamos National Laboratory. The Small Secure Transportable Autonomous Reactor (SSTAR) was developed under DOE's Generation IV program with participation from Lawrence Livermore, Argonne, and Los Alamos National Laboratories, in conjunction with the University of California and Texas A&M University. Other active designs of interest in the US include the Next Generation Nuclear Plant under development by Westinghouse, General Atomics, and Areva; General Electric's Power Reactor Inherently Safe Module (PRISM); and Toshiba's Super Safe Small and Simple (4S). [12]

While a few experimental prototypes have been built, commercialization of small nuclear reactors is still at least 5-10 years away. None of the designs under development have been certified by the Nuclear Regulatory Commission. The design certification process for traditional light water reactors typically takes 2-3 years, with an additional 2 years or longer for site licensing to build and operate the reactor. Certifications for designs using new technologies are expected to take longer.[13] The NRC estimated in 2008 that it would take 5 years to develop necessary analytical tools, data, regulatory guides, and standard review plans for confirmatory safety analyses and license review, and another 4-5 years to conduct the licensing review for new technologies.[14]

[9] Ingersoll, D.
[10] Macon, W. Nuclear Power Plants on Military Installations. October 28, 2009. https://docs.google.com/fileview?id=0B83Q27_xggOTMDUwYTdlMjctNDgxMC00NzAxLWI4M2UtZTZkNDYzNzE0MzJi&hl=en
[11] Ingersoll, D.
[12] Ingersoll, D.
[13] Targeted News Service. Chairman Gregory B. Jaczko Responds to Senator Jeff Bingaman Submitting NRC's Comments Regarding S. 2052. December 10, 2009.
[14] Macon, W.

In a 2001 report, DOE estimated the cost of electricity for a generic 50 MWe small reactor would be 5.4-10.7 cents/kWh, and 10.4-24.3 cents/kWh for a 10 MWe reactor.[15] Capital cost estimates range from $1000-$4000/kW. At these prices small nuclear reactors would provide power at rates competitive with fossil fuel and renewable energy generation technologies.

Small nuclear reactors are not a currently available energy generation technology. Many factors related to the technology, regulatory process, cost, and safety are still being developed and will contribute to their future commercial viability. The following DOE national laboratories are conducting research on small nuclear reactors.

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[15] U.S. Department of Energy Office of Nuclear Energy, Science, and Technology. Report to Congress on Small Modular Nuclear Reactors, May 2001. http://www.ne.doe.gov/pdfFiles/Cong-Rpt-may01.pdf