The Oil Drum
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Possibilities for Small Modular Nuclear Reactors?

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This is a guest post by Rod Adams, author of Atomic Insights Blog.

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Recently, however, a growing body of plant designers, utility companies, government agencies and financial players are recognizing that smaller plants can take advantage of greater opportunities to apply lessons learned, take advantage of the engineering and tooling savings possible with higher numbers of units and better meet customer needs in terms of capacity additions and financing. The resulting systems are a welcome addition to the nuclear power plant menu, which has previously been limited to one size - extra large.

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This is a guest post by Rod Adams, author of Atomic Insights Blog. Rod's Oil Drum name is atomicrod. Rod earned his initial atomic knowledge while serving as an engineering officer on US nuclear powered submarines throughout the 1980s. He founded Adams Atomic Engines, Inc. in 1993 to produce small modular reactors, but put that company to sleep in 1996, when the price of oil dipped to $10 per barrel and natural gas sold for as low as $1.60 per million BTU.

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When Westinghouse, General Electric and their international competitors first learned that uranium was a incredible source of heat energy, they were huge, well established firms in the business of building equipment used for generating electrical power. Each had made a significant investment in the infrastructure necessary for producing central station electrical power on a massive scale.

Experience had taught them that larger power stations could produce cheaper electricity and that electricity from central power stations could be effectively distributed to a large number of customers whose varying needs allowed the capital investment in the power station to be most effectively shared between all customers.

Their experience was even codified by textbook authors with a rule of thumb that said that the cost of a piece of production machinery would vary by the throughput raised to the 0.6 power. (According to this thumb rule, a pump that could pump 10 times as much fluid as another pump of similar design and function should cost only four times as much as the smaller pump.) They, and their utility customers, understood that it was much cheaper to deliver bulk fuel by pipeline, ships, barges, or rail than to distribute smaller quantities of fuel in trucks to a network of small plants.

Just as individuals make judgments based on their experience of what has worked in the past, so do corporations. It was the collective judgment of the nuclear pioneers that the same rules of thumb that had worked so well for fossil plants would apply to nuclear plants.

Though accurate cost data is difficult to obtain, it is safe to say that there was no predictable relationship between the size of a nuclear power plant and its cost. Despite the graphs drawn in early nuclear engineering texts-which were based on scanty data from less than ten completed plants-there was not a steadily decreasing cost per kilowatt of capacity for larger plants.

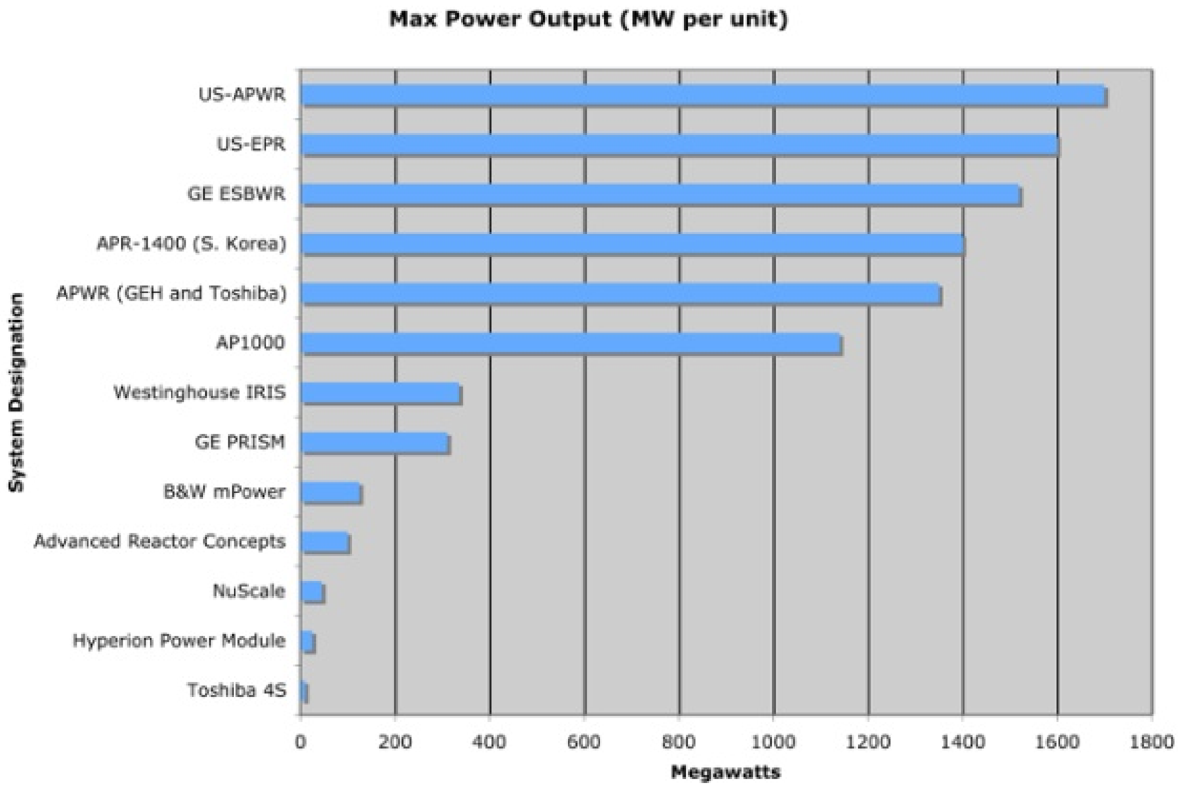
It is possible for engineers to make incredibly complex calculations without a single math error that still come up with a wrong answer if they use a model based on incorrect assumptions. That appears to be the case with the "bigger is better" model used by nuclear plant designers and marketers.

Though the "economy of scale" did not work for the first nuclear age, there is some evidence that a different economic rule did apply. That rule is what is often referred to as the experience curve. According to several detailed studies, it appears that when similar plants were built by the same organization, the follow-on plants cost less to build. According to a RAND Corporation study, "a doubling in the number of reactors [built by an architect-engineer] results in a 5 percent reduction in both construction time and capital cost."

This idea is significant. It tells us that nuclear power is no different conceptually than hundreds of other new technologies.

> The principle that Ford discovered is now known as the experience curve. . . It ordains that in any business, in any era, in any capitalist competition, unit costs tend to decline in predictable proportion to accumulated experience: the total number of units sold. Whatever the product (cars or computers, pounds of limestone, thousands of transistors, millions of pounds of nylon, or billions of phone calls) and whatever the performance of companies jumping on and off the curve, unit costs in the industry as a whole, adjusted for inflation, will tend to drop between 20 and 30 percent with every doubling in accumulated output.
> George Guilder *Recapturing the Spirit of Enterprise Updated for the 1990s*, ICS Press, San Francisco, CA. p. 195

These ideas are not new. I copied most of the above paragraphs from an article that I published on Atomic Insights in May 1996 titled *Economy of Scale? Is Bigger Better?*.



Apparently, the ideas that I pointed to fourteen years ago have also occurred to a number of nuclear plant designers and business decision makers who noticed that the estimates for the traditional sized nuclear plants kept expanding at much greater than the rate of inflation as they became more detailed and closer to reality. The complexities of putting together the very large systems and projects kept adding to the risk, which added to the cost and complexity of financing which added to the project complexity by requiring additional partners - including government agencies and public subsidies.

Some frustrated nuclear plant designers, inspired by talking with customers about their needs and remembering what was technically possible in terms of nuclear reactor sizing determined that they might be able to solve some of the cost and schedule complaints by a complete rethinking of the old economy of scale paradigm. For anyone who has been paying attention during the past five years or so, the names of Hyperion, NuScale and Toshiba 4S have been increasingly frequent terms of discussion as start-ups and some established vendors began designing nuclear fission based systems sized at 10, 25, or 45 MWe, which is a radical departure from the 1000 MWe (plus) sizes of the AP1000 (Westinghouse), ESBWR (GE-Hitachi), or EPR (Areva).

Initially, the project leaders for these new designs thought about using them in distributed remote locations where power is either not available or is being supplied by expensively delivered diesel fuel. John (Grizz) Deal and his sister, Deborah Deal Blackwell, the Hyperion Power Generation founders thought about the how a simple, infrequently fueled nuclear plant could supply power to a remote area for up to a decade without refueling. They recognized the value that such a system could provide to the previously powerless people living in that remote area.

The system could provide power for refrigeration, water treatment and distribution systems, communications systems, and reliable, flicker free lighting. Unfortunately, the specific technologies needed for the Hyperion design - liquid metal (Pb-Bi) cooling and uranium nitride fuel elements - are not in commercial use. They hve been used in several specialized reactors and proven to work reliably and safely, but starting up a new supply chain is just one of the many hurdles that Hyperion is diligently working to overcome. The Toshiba 4S sodium cooled power system faces similar challenges, but both concepts have their fans and both are moving forward.

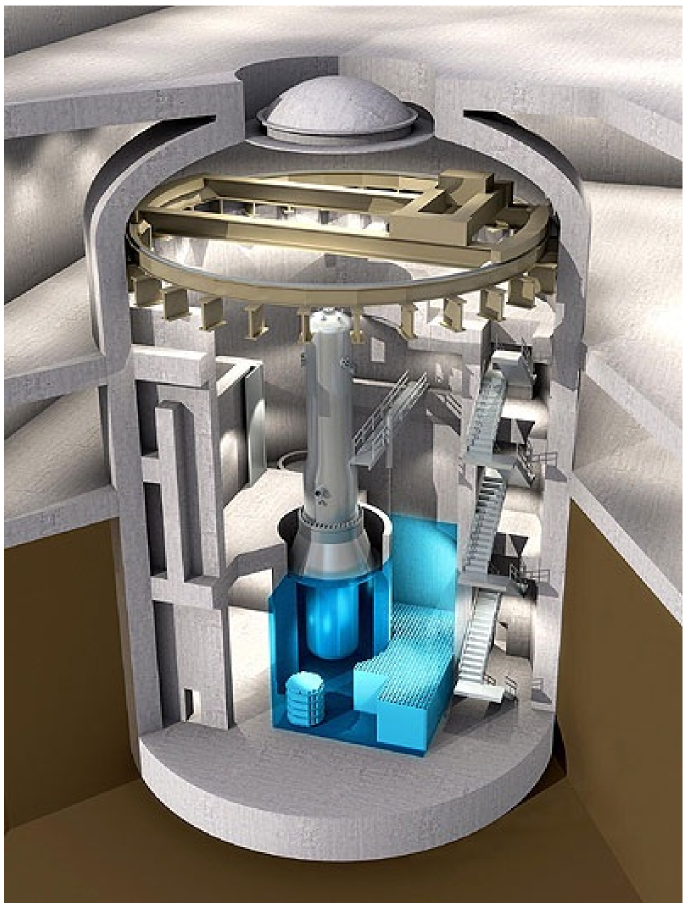
A trio of project teams has recognized that the concept of small does not mean that you have to start from scratch with the supply chain, training programs, and safety analysis; it is possible to do a redesign of light water reactors from the ground up to produce an economical design that achieves economy by both simplification and increased unit volume. All three of the teams - NuScale, B&W and Westinghouse - have designed systems that put the entire primary plant into a single pressure vessel. This choice eliminates the potential for a large pipe break loss of coolant accident. They have all chosen to include a large volume of water - relative to the core power output - that provides operators with lengthy interval between any conceivable accident and required operator action. They also have chosen passive safety systems that do not require any outside power sources to operate, so they expect to be able to prove that they can meet existing safety criteria without redundant power sources. All of the iPWR systems envision using fuel assemblies that are essentially the same as commercial nuclear plant fuel elements - but they will be shorter and there will be fewer assemblies in each core. All of the systems have been designed for the post 911 security and safety considerations including the aircraft impact rule through the use of below grade installation.

NuScale Power Module

After those common traits, there are some differences in technical features that might be attractive to different kinds of customers. NuScale's module size is 45 MWe and it does not contain any coolant pumps; the system uses natural circulation both in operation and when shut down. The company expects that customers will want to plan for the eventual installation of 6 (270 MWe) or 12 (540 MWe) units on a single site.

NuScale has selected Kiewit as its Engineering, Procurement, and Construction (EPC) contractor. Together the two companies have completed a detailed, bottom up price estimate yielding an expected cost of between $4,000 and $4,400 per kilowatt of capacity, depending on whether the customer wants a 6 or 12 pack installation. NuScale has informed the NRC that it will be filing its license application in the first half of 2012. Much of its system and safety analysis work is backed up with actual data from the 1/3 scale integrated system loop (with electric heaters to simulate the nuclear core) installed at Oregon State University.

Westinghouse is a bit further out with its 335 MWe IRIS, but it plans to submit a license application by the end of 2014. Part of the delay is due to a company focus on completing the revised license application for the AP1000 and quickly resolving any of the inevitable engineering issues that pop up during plant construction.



mPower in underground containment

The integrated pressurized water reactor (iPWR) that is gaining the most buzz from the business community and political leaders, however, is the 125 MWe mPower™. Yesterday, Bechtel Corporation, one of the largest privately held companies in the United States, with 57,000 employees and $30.8 billion in 2009 revenue, announced that it was joining with B&W as a 20% partner in an exclusive alliance that they have branded as Generation mPower to build complete, turn-key power plants.

B&W has an already existing and ASME 'N-stamp' certified US manufacturing base and 50 years worth of experience in building nearly all of the components required for the small, modular light water reactors that power ships and submarines. Bechtel has either built or participated in major renovation projects at 64 of the 104 nuclear plants operating in the United States.

The mPower™ modules will be about the same size as the NuScale modules, but each module will produce about 2.5 times as much power as a NuScale module because they include submerged reactor coolant pumps to provide forced flow through the core. The system is designed to supply a sufficient quantity of natural circulation to provide core cooling after shutdown without any pumps running, thus maintaining the passive safety characteristic. Like NuScale, Generation mPower expects that customers for its plants will probably want to plan to install multiple units on a single site, though they might start with just one or two and add additional units gradually over time. Generation mPower has informed the NRC that it will be submitted a design certification application by the end of 2012; that application might be filed at the same time as a construction and operating license for the first of a kind unit.

The iPWR projects are all positioning themselves to obtain licenses in the United States, to sell their first units to US customers, and to get the involvement of experienced nuclear utility companies. The project sponsors have determined that their smaller unit sizes will be attractive power sources for certain types of customers that would face an insurmountable barrier in trying to build one of the extra large plants. Modular power stations can be financed in phases with revenue generation increments that are more closely matched with demand growth. Several cooperative electric utility companies have joined in the user groups that have formed to help provide both mPower and NuScale with the customer point of view as the system designers complete their detailed work.

Both NuScale and Generation mPower have determined that the proposed unit sizes more closely match the capacity currently provided by aging coal plants and might be considered as appropriate replacements once those coal plants reach the end of their life. Both the Tennessee Valley Authority and FirstEnergy have expressed interest in finding out more about how the proposed modules might help them reuse existing sites that currently host obsolete coal power plants and are not even close to natural gas pipelines.

A growing body of plant designers, utility companies, government agencies and financial players are recognizing that smaller plants can take advantage of greater opportunities to apply lessons learned, take advantage of the engineering and tooling savings possible with higher numbers of units and better meet customer needs in terms of capacity additions and financing. The resulting systems are a welcome addition to the nuclear power plant menu, which has previously been limited to one size - extra large. Developing a broader range of system choices using nuclear fission energy could have a measurable impact on segments of the energy market that have been most often served by burning distillate fuel or natural gas. Small modular reactors offer a reason to be optimistic that human society will have access to all of the energy that it needs for increased prosperity for larger portion of the population.