Argonne's David Wade: On the development of small modular reactors

The Department of Energy is working toward the development of small reactors that can be placed in remote locations.

Design work on small modular reactors (SMRs) is ongoing at the Department of Energy's Argonne National Laboratory, in Illinois. The reactors include the Encapsulated Nuclear Heat Source (ENHS), the STAR-LM (Secure Transportable Autonomous Reactor-Liquid Metal), STAR-H2 (for the production of hydrogen) and S-STAR (a small version of the STAR). The designs all include modularity, increased safety margins, suitability to local electrical grid requirements, design flexibility for applications beyond power generation, and lower initial capital investment.

The STAR group at Argonne working under Phillip Finck, deputy associate laboratory director for engineering research, includes David Wade, James Sienici, Won Sik Yang, and Anton Moissetsev.

Wade, senior technical advisor to Finck, talked in depth about SMR designs with Rick Michal, *NN* Senior Editor.

Wade: "We saw the challenges posed to remote communities in providing electric power."

Why is Argonne working on small modular reactor designs?

We saw the challenges posed to remote communities in providing electric power. In those locales—for example, in parts of Alaska and Hawaii—it is likely that there will be a shortage of trained personnel, higher expense, difficulty in shipping and storing fuel, and power requirements that are relatively small and variable. A power generating system serving such areas must be very reliable, as remoteness implies restricted accessibility for repair crews.

Argonne undertook the technical evaluation of existing SMR designs and proposed SMR concepts from domestic and foreign sources. Based on the current power usage of typical remote communities in the United States, a maximum electricity generating capacity of 50 MWe was set for the selected SMR designs and concepts.

There also is an international need for smaller power units. Many of the conditions faced in Alaska and Hawaii exist around the world. Examples can be found in the Siberian region of Russia, which is similar to Alaska, while the small islands in Japan and other island nations have conditions that are similar to Hawaii. For many nations, additional challenges include the lack of any reliable electricity grid, requiring power to be generated more locally, even for larger population centers. Since electricity demand per capita is presently very low in many of these nations, only smaller power plants would be useful. Based on design work being performed in other countries on small nuclear power plants, the power output range of interest appears to be 20 MWe to 50 MWe.

What are the characteristics of these small plants?

The characteristics were evaluated on the basis of their ability to satisfy the relevant criteria for new generation plants in isolated locations. These characteristics are inherent safety, cost-effectiveness, resistance to sabotage and diversion of nuclear materials, infrequent refueling, the level of factory fabrication, and transportability to remote sites.

Can you describe the modularity of the plants?

For small plants, the term "modular" can describe a single reactor that is assembled from factory-fabricated modules, where each module represents a portion of the finished plant. The use of modules implies that assembly has been reduced to limited activities such as connecting the modules, greatly reducing the amount of field work required, and simplifying completion. Taking this approach, this use of modules increases the ability to deploy a reactor in remote locations.

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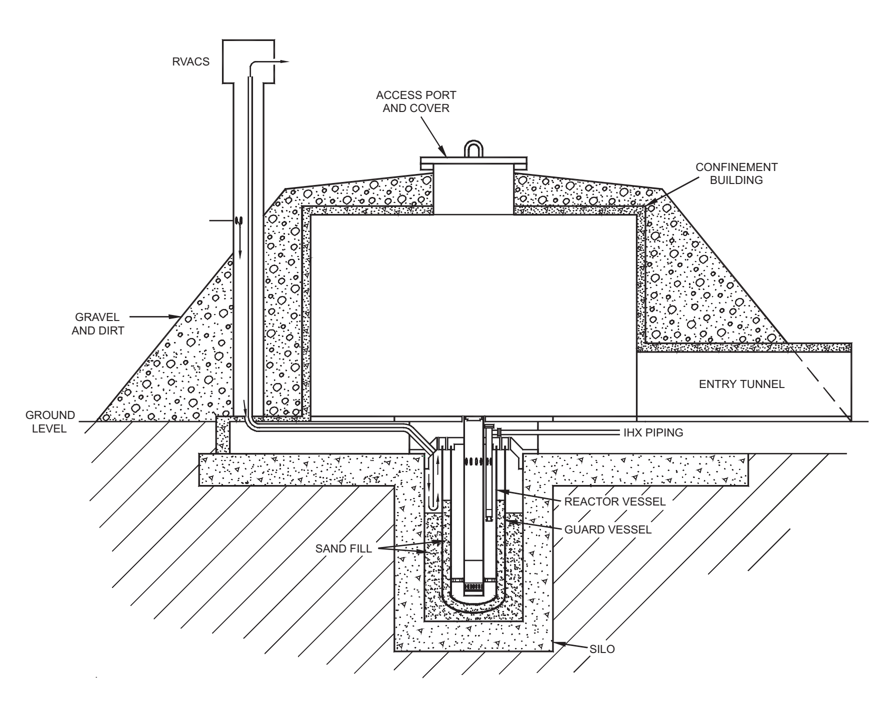
Are there specific designs that Argonne is working on?

The two new SMR designs are the Encapsulated Nuclear Heat Source (ENHS) and the STAR-H2.

The ENHS is a concept being developed under the Department of Energy's Nuclear Energy Research Initiative (NERI) program by a consortium led by the University of California, Berkeley. It is a liquid metal–cooled reactor that can use either lead or a lead-bismuth alloy as the reactor coolant. As opposed to sodium as the traditional liquid-metal coolant, the lead-based coolants are chemically inert with air and water, have higher boiling temperatures, and better heat transfer characteristics for natural circulation. The ENHS has a very long core life, and it uses natural circulation to cool the reactor core and to produce steam to drive the turbine. The ENHS concept relies on autonomous control; that is, after the reactor is brought to full power, variation in power output follows the electricity generating needs automatically (i.e., load following) by using temperature feedback from the varying steam pressure and feedwater flow.



Underground reactor: The STAR-H2 would be protected from external hazards, as this concept drawing illustrates, by a guard vessel, sand, gravel, and dirt. (Source: Department of Energy)

How long is the ENHS core life?

The ENHS can operate at full power for 15 years. The concept is based on the idea of encapsulating the reactor core inside its own vessel as a module, with no external piping connections. The core is located in a central vertical cylinder inside the vessel.

The ENHS module is manufactured and fueled in the factory, and shipped to the site as a sealed unit with solidified lead or lead-bismuth filling the vessel up to the upper level of the fuel rods. With no mechanical connections between the reactor module and the secondary system, the module is easy to install and replace, similar to using a battery. At the end of its life, the ENHS module can be removed from the reactor pool and stored on site until the decay heat drops to a level that lets the coolant solidify. The module with the solidified coolant would then serve as a shipping cask. The total weight of an ENHS module when fueled and when loaded with lead-bismuth to the upper core level is estimated to be 300 tons, which could pose a shipping challenge, especially to remote areas.

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What about the STAR-H2?

STAR-H2 is a variant of the Secure Transportable Autonomous Reactor-Liquid Metal (STAR-LM), which has been adapted for operation within a hydrogen economy. In this application, the basic STAR-LM unit is modified to heat helium or another heat transport gas to a high temperature that can be used in a water cracking cycle, thus producing hydrogen for power production and oxygen for industrial uses. The waste heat from this process can be applied as process heat for industry, district heating, or desalination purposes.

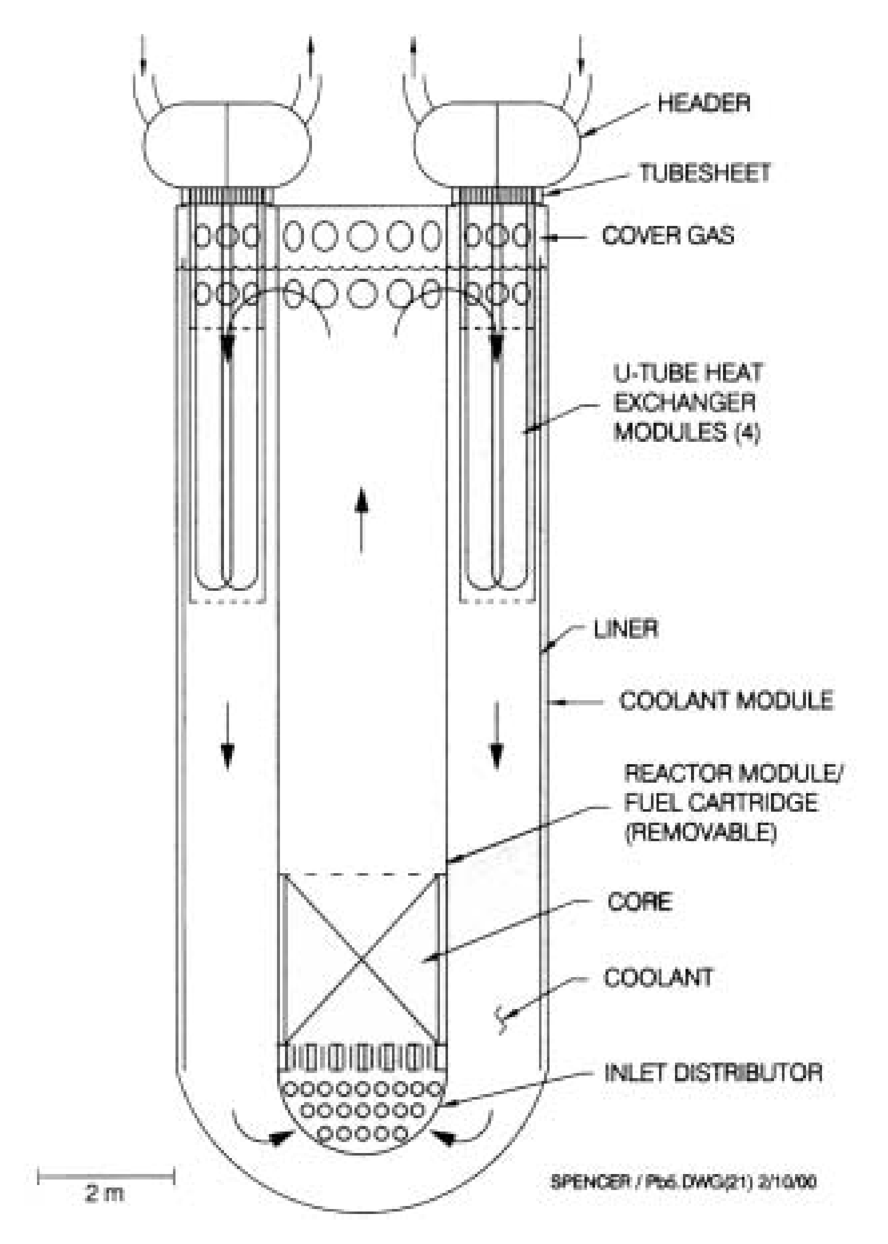
The STAR-H2 program also is a NERI project, approved and initially funded in 2000, and it has multiple participants: Argonne, Texas A&M University, General Electric, and international collaborators. The project also maximizes the use of the nuclear heat produced compared to a more conventional steam turbine generation cycle by adding a topping cycle—for hydrogen generation—and a bottoming cycle—for desalination or industrial processes.

How did you decide on the ENHS and the STAR-H2 designs?

The Russians declassified their lead-bismuth activities in a major meeting in the late 1990s. They had been using lead-bismuth for submarine reactors, and that technology was made available to the world at a conference they held in 1998. Prior to that, the accelerator-driven system people had already been looking at lead-bismuth–cooled systems since the early 1990s.

When we looked at the Russian technology, we realized that we wanted a natural circulation coolant that would be suitable for the kinds of reactors that could be put in a developing country—ones that would be extraordinarily safe and that would require small operating crews. Natural circulation was good, and that can be achieved with lead or lead-bismuth. We can open the distance between the fuel pins and not cause the neutrons to be slowed down or absorbed much because lead and lead-bismuth don't slow neutrons or absorb them as much as would other coolants. This was the driving force that got us started looking at lead or lead-bismuth–cooled fast reactors.

Because we wanted the reactors to be refueled very infrequently—perhaps every 10 years to every 20 years, and some designs even strive for a 30-year refueling interval—we were looking for fast spectrum reactors that would have an internal conversion ratio of about 1, so that as the fissile material was burned out, it would be regenerating fissile material to match it. That would make the loss of reactivity with burnup close to zero. That is a feature that allows us to achieve passive safety and passive load following.



STAR-LM: This lead-cooled, natural circulation 400-MWth fast reactor would have a 20-year core life. (Source: Department of Energy)

Could you talk more about refueling these reactors?

We are looking into the idea of regional fuel cycle centers, an idea that was discussed first in the late 1970s. It never took off because recycle has not been a major part of nuclear energy. But because of the sustainability issue, we know eventually we're going to have to recycle. If we could do it at regional fuel cycle centers that support these long refueling interval reactors, we could reduce the costs of safeguards oversight. This could be done by having no more than a dozen fuel cycle facility sites throughout the world. We would get economy-of-scale benefits from the recycle technology and at the same time provide nonproliferation features.

Again, at the same time, because of the long refueling interval, legal arrangements could be made to guarantee services from the regional centers to nations that decided to forego placing an indigenous fuel cycle within their borders. This is an idea that we are investigating. It's not universally agreed that this is the best way to do it, but it's one we are looking into.

How far away are we from any kind of demonstration project for one of these designs?

I think a demonstration project is not going to happen in five or 10 years. It might be between 10 and 15 years.

Are there any cost figures for building one of these designs?

No, we haven't done a cost estimate yet. But the reactor would be factory-fabricated and moved to the site, connected to a non-safety-grade balance of plant with a very short onsite construction interval. The hope is that these features would overcome the loss of economy-of-scale.

Are there any particular challenges popping up for these designs?

The compatibility of structural materials with lead is one. In the case of the Brayton cycle, we're interested in a supercritical carbon dioxide Brayton cycle that was invented in the late 1960s but was never actually developed. So, we and researchers at MIT are in the process of trying to develop it. Its feature is that the equipment is extraordinarily small. We're hopeful that if we can develop this supercritical CO_2 cycle, it will have a very low cost in the balance of plant. By the way, at reasonable outlet temperature—500 °C—we can theoretically get conversion efficiencies of heat to electricity of between 40 and 45 percent, which is much better than would be possible with an ideal gas like a helium Brayton cycle.

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What about the plant staffing issue?

We haven't yet tackled the staffing issue, but the hope is that with a nonsafety-grade balance of plant, and with simplified components of a Brayton cycle instead of a steam Rankine cycle, we could cut down on the number of operating staff and their required skill level. If we can achieve this passive safety/passive load problem, then any combination of mechanical or human error in the balance of plant should not cause damage to the reactor. This would be a fantastic advantage in both the number of operating staff and their skill level.

Regarding security, the SMR designs are inherently safe, but in the post-9/11 world if these reactors were in remote areas, what kind of targets would they be for someone looking to do harm?

We are still in the very early stages, but the kind of siting we're looking at is to put them in underground silos, where they would be naturally protected. In addition, the containment would be similar to those of modern sodium reactors, with a guard vessel and a small-volume dome over the top. The dome, which would probably be metallic, would be the size of the reactor vessel itself. Meanwhile, the confinement building would provide working space, but it would not have a containment function. We're developing conceptual drawings, but we have no real structural analysis of putting a berm over the top of the building.

How confident are you that your work will result in the building of these sorts of reactors?

We're confident. If we look at the next 50 years and the projections for energy deployment, we see that the developed countries are going to be dominated by the developing countries by the middle of the century. They are simply going to be adding more capacity. Consistent with the DOE's Generation IV program, we were trying to think of a concept that would be sustainable, that would be deployable worldwide, that would have nonproliferation features, that would be passively safe, and would be affordable. That's what's been driving us. NN