make heat, and they're looking at what their options are.

There is some interest in the traditional nuclear industry in this technology. A couple of utilities are showing interest in the high-temperature gas reactor. Some of that interest is in producing hydrogen and selling it into the pipeline that exists along the Gulf coast. Other interest is in being the owner-operator of the nuclear facility that supplies process heat to industry. The company that has been most vocal about that is Entergy.

Question: There is quite a bit of international interest in this technology—in South Africa, and General Atomics has worked with the Russians. It has been proposed that the U.S. program could advance more quickly by taking advantage of this work.

The Westinghouse interests and the South Africa Pebble Bed Modular Reactor (PBMR) people participate in this emerging commercial alliance. There's an ongoing conversation as to how we can achieve the benefits from the work that has already been done in South Africa. You have a competitive marketplace, and other vendors have interests in this. There are three teams: the Westinghouse team, which includes the PBMR group; an Areva team; and a General Atomics team. About 26 international companies are involved, and we are discussing how we use work that has already been done—by the South Africans and also the Russians, in their plutonium burner work with General Atomics—how we bring in the experience that goes back decades, and also the current work, that has been done.

Question: One of the suggestions to accelerate the program was to start with a smaller reactor, at a lower temperature, which is not so challenging from a materials standpoint.

In fact, irrespective of the size, we will start at a lower temperature, because technically we need to step our way up. We are starting at a lower temperature than originally conceived of for the very-high-temperature reactor, which was in excess of 1,000°C. In the range of 950-1,000°, you get to the point where conventional metals will not work. The review group said to get below that temperature, and we have taken that step.

The second step in that discussion is, what temperature do we need for the process applications? The third step, is, at what temperature should we start the demonstration activity, so we are technologically successful, and to what extent can that reduce the time required? This is a very active conversation. I would not be surprised that when that is complete, in about a year, that we'll be lower than 950°C, in the range of 850-900°, which makes a big difference.

The three teams of companies will have their pre-conceptual design reports done in the September time frame, with opinions and recommendations. But temperature alone is not the only issue. The other is licensing time by the Nuclear Regulatory Commission, also being actively discussed.

Figure 1
ARTIST'S ILLUSTRATION OF A PBMR PLANT
The first prototype PBMR is expected to be online by 2013, and a plant to fabricate the fuel pebbles is now under construction. The first reactor will be built at Koeberg, near Cape Town, and the pilot fuel plant is being built at Pelindaba, near Pretoria. South Africa has an ambitious program planned for the mass production of PBMRs for domestic use and export.
Source: Courtesy of PBMR

Fourth-Generation Reactors Are Key to World's Nuclear Future

by Marjorie Mazel Hecht

By 2050, the world will need 6,000 more nuclear reactors in order to keep up with population growth and electricity demand. We will need all kinds of reactors: large advanced reactors for industrialized nations, fast reactors (breeders) that can create more new fuel than they burn, floating nuclear plants, thorium-fueled reactors, and other innovative designs. But the workhorse of the next generation of nuclear reactors will be the modular high-temperature gas-cooled reactor, both the Pebble Bed Modular Reactor (PBMR) and the Gas-Turbine High Temperature Reactor (GT-MHR), because of their inherent safety and versatility.

The PBMR, originally a German design (a 30-megawatt prototype operated there from 1967-1989), is being built in South Africa (Figure 1). The GT-MHR, designed by San Diego-based General Atomics, is being engineered in prototype in Russia, with the aim of burning excess plutonium from decommissioned weapons. Also, China has had a small (10 megawatt)

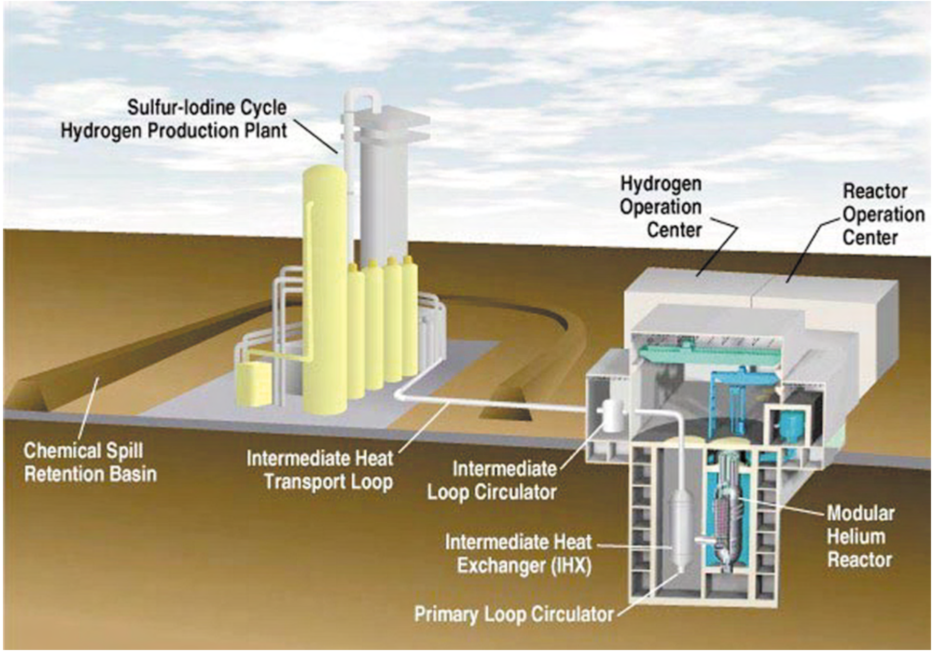


Figure 2
GT-MHR HYDROGEN PRODUCTION
This General Atomics design couples a modular helium reactor, the GT-MHR, to a sulfur-iodine cycle hydrogen production plant. The sulfur-iodine cycle, which uses coupled chemical reactions and the heat from the high-temperature reactor, is the most promising thermochemical method for hydrogen production.
Courtesy of General Atomics

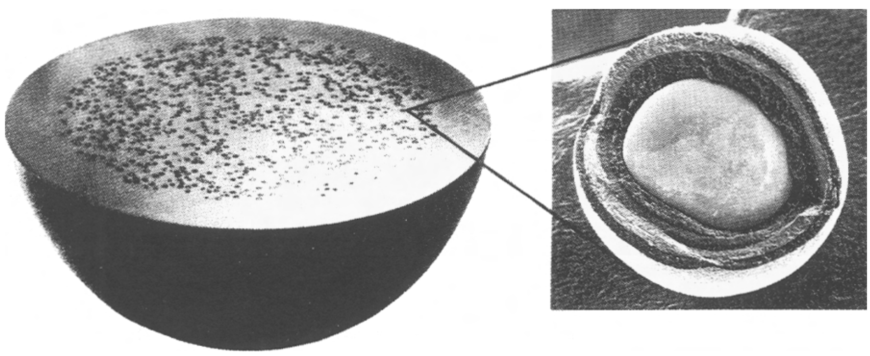
high-temperature reactor of the pebble bed design in operation since 2000, with plans for a large-scale demonstration reactor by 2010. Japan also has a high-temperature test reactor.

One advantage of these reactors is that they are small enough to be modularly produced on an assembly line and shipped to the plant site for assembly, thus cutting the production costs. The nuclear site can be configured to start with one or two units and built up to six or eight, as needed, making use of a single control building. Thus a developing country, where the electricity grid is small, can start off with one unit, and build up as the country develops.

Another advantage is their high-temperature output. For the GT-MHR, output is almost three times hotter than today's conventional reactors—1,560°F, compared to 600°F. (The PBMR output is about the same.) These high temperatures can be coupled with a wide range of industrial processing, from steel-making to hydrogen production for fuel (Figure 2).

The PBMR is a 165-megawatt plant, while the GT-MHR is a 285-megawatt plant. Both have passive and inherent safety features that make a meltdown impossible. The reactors can shut down without any operator intervention.

These reactors are meltdown proof because of their unique fuel design (Figure 3). Tiny uranium fuel particles are encased in ceramic spheres (0.03 inch or 0.75 millimeter for the GT-MHR), which serve as "containment buildings" for the fission process. The several concentric layers of temperature-resistant materials—porous carbon, pyrolytic carbon, and silicon carbide, "contain" the fission reaction of the uranium, even at very high temperatures. The overall design prevents the reactor from ever getting hot enough to melt the



Courtesy of PBMR

Figure 3
CROSS-SECTION VIEW OF FUEL PEBBLE
A cutaway view of a coated PBMR fuel particle is at right. Each particle has a 0.5 mm kernel of uranium dioxide surrounded by several concentric layers of high-temperature-resistant ceramics that "contain" the fission reaction. The coated fuel particles are then embedded in a graphite matrix and formed into fuel spheres the size of tennis balls, about 60-mm diameter, which circulate in the reactor core.

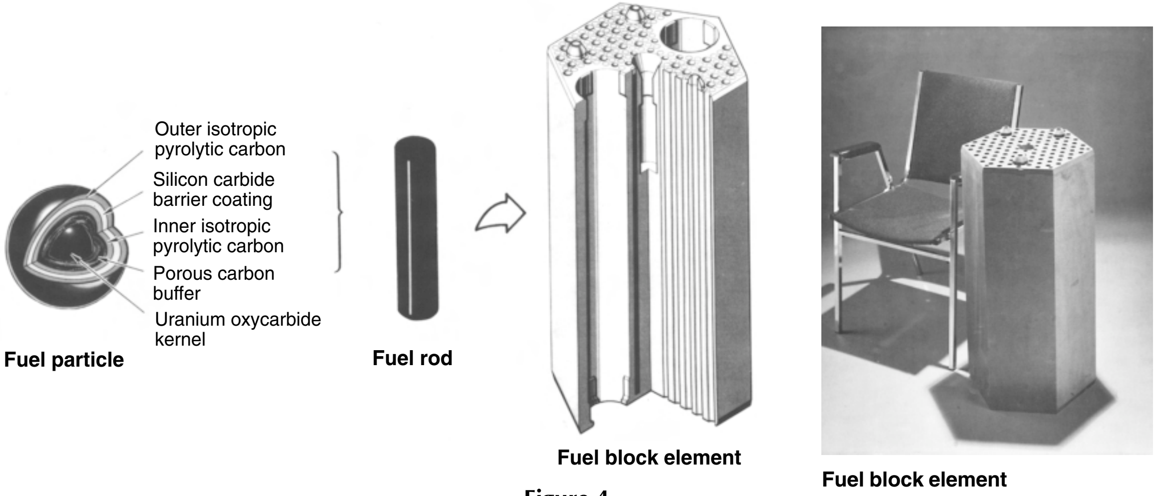


Figure 4
GT-MHR FUEL COMPONENTS

The tiny fuel pellet (a) is about 0.03 inch in diameter. At the center is a kernel of fissile fuel, uranium oxycarbide, which is coated with a graphite buffer and then surrounded by three successive layers of carbon compounds. The fuel particles are mixed with graphite and formed into cylindrical fuel rods, about 2 inches long (b). These rods are then inserted into holes drilled in the hexagonal graphite fuel element blocks (c) and (d). These are 14 inches wide and 31 inches long. The fuel blocks, which also have helium coolant channels, are then stacked in the reactor core.

ceramic spheres that surround the nuclear fuel.

The fuel particles can withstand heat of 3,632˚F, and the reactor core temperature remains below 2,912˚F. In fact, the fuel pebbles can withstand temperatures at which the metallic fuel rods in conventional light water reactors would fail.

In the GT-MHR, the spheres are mixed with graphite and shaped into cylindrical fuel rods, which are then inserted into hexagonal fuel blocks that make up the reactor core (Figure 4). General Atomics pioneered this fuel particle design in the 1950s, and operated two high-temperature reactors in the United States.

The PBMR fuel design is similar. Tiny nuclear fuel particles are coated with layers of ceramics. But unlike the GT-MHR, the fuel particles are then embedded into fuel balls the size of tennis balls. Each of these balls contains about 15,000 fuel particles and about one-quarter ounce of uranium. The balls, 456,000 of them, circulate around the reactor core. One advantage of this design is that the reactor can be continuously refueled, adding new fuel pebbles at the top, and removing spent fuel pebbles from the bottom of the reactor.

Efficiency and Safety

The high-temperature output of these reactors gives them greater generating efficiency, in addition to allowing a wide range of industrial applications. Both use a direct-conversion gas turbine, with no steam cycle—a big improvement. The heat is carried by the helium gas, which is also the coolant. This simplifies the system, reducing material requirements, and increases efficiency. Other technological breakthroughs have also contributed to simplifying the design and making the reactors more efficient. The GT-MHR is 50 percent more efficient than conventional light-water nuclear reactors.

Both the GT-MHR and the PBMR are located underground, with the auxiliary systems and control room above ground. The overall design of the reactor contributes to its safety. In addition to the usual control rods, which can slow down the fission process, there are two coolant systems, a primary system and a shutdown coolant system. If both of these were to fail, the reactor is designed to shut down on its own. There is a passive back-up system, whereby the heat from the reactor core is transferred by natural conduction to the reactor walls, which naturally convect the heat to an external sink. The concrete walls of the underground structure are lined with water-cooled panels to absorb the core heat from the vessel walls. Should these panels fail, the concrete of the structure alone is designed to absorb the heat.

In any type of loss-of-coolant accident, the reactor can withstand the heat without any operator intervention.