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 1967-89), 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) 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

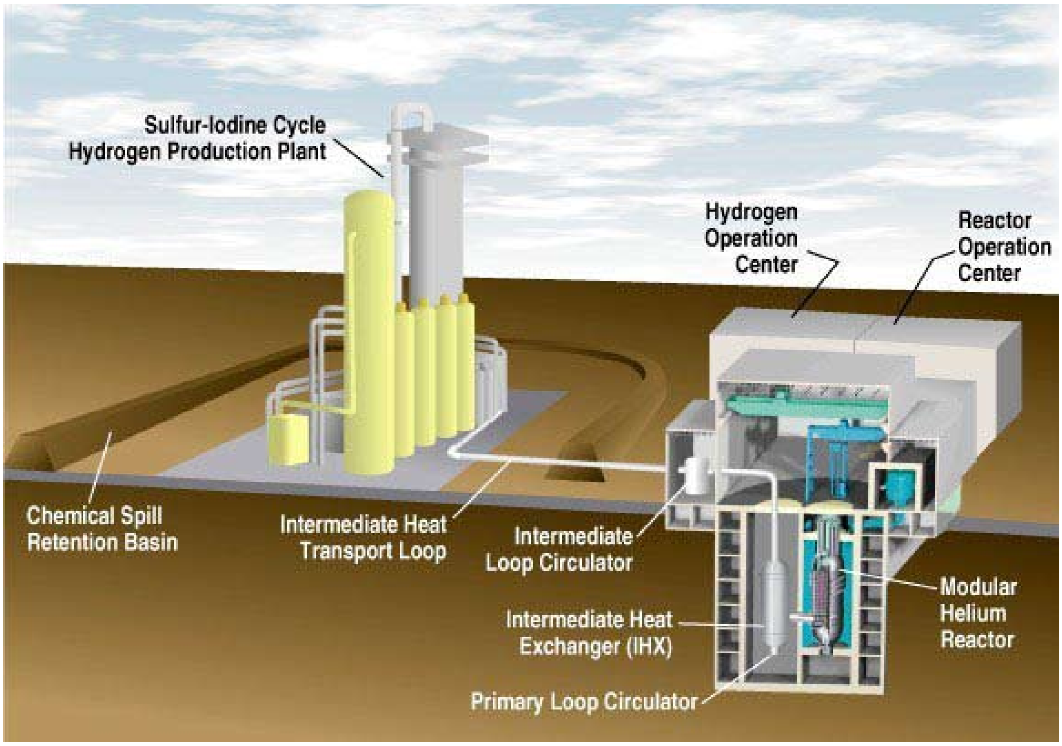
FIGURE 1
Artist's Illustration of a PBMR Plant

Courtesy of PBMR

The first prototype PBMR is expected to be online by 2013. PBMR is also constructing a plant to fabricate the fuel pebbles. The demonstration reactor will be built at Koeberg near Cape Town, and the pilot fuel plant at Pelindaba near Pretoria. South Africa has an ambitious program planned for the mass production of PBMRs for domestic use and export.

FIGURE 2

GT-MHR Hydrogen Production



Courtesy of General Atomic

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.

build up as the country develops.

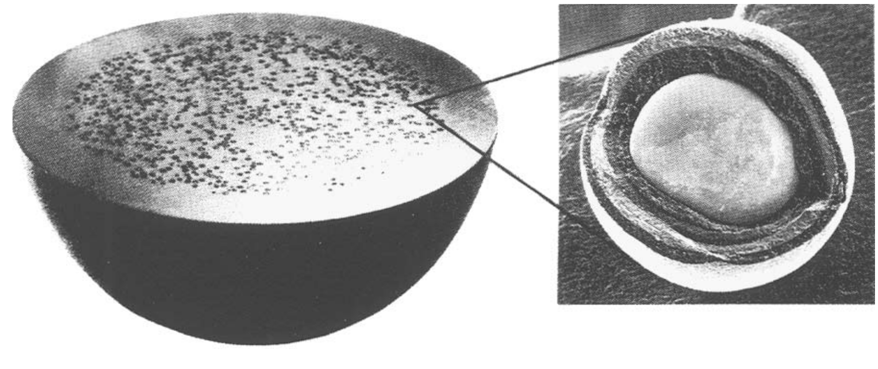
Another advantage is their high temperature output. For the GT-MHR, output is almost three times hotter than today's conventional reactors—1,560°F, compared to 600°F. (The PBMR output is about the same.) These high temperatures can be coupled with a wide range of industrial processing, from steel-making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

FIGURE 3

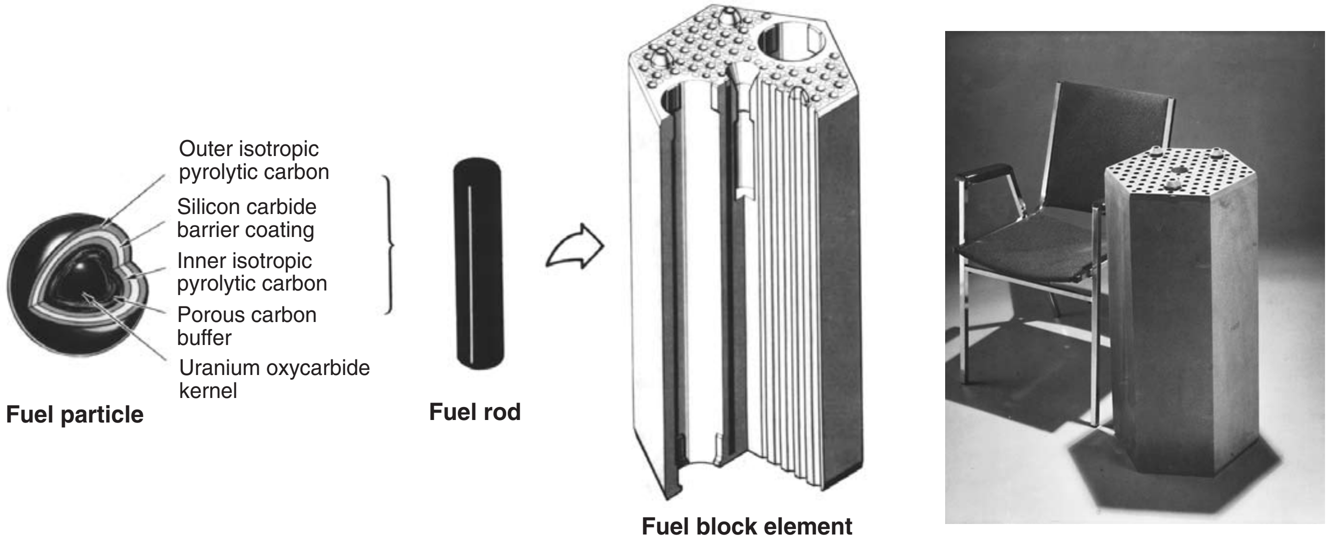
Cross-Section View of Fuel Pebble



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



Fuel particle **Fuel rod** **Fuel block element** **Fuel block element**

The tiny fuel pellet (left) 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. These rods are then inserted into holes drilled in the hexagonal graphite fuel element blocks. These are 14 inches wide and 31 incles 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 and increases efficiency. Other technological breakthroughs have also contributed to simplifying the design and making the reactors more efficient. The GT-MHR is 50% more efficient than conventional light-water nuclear reactors.

Both of these reactors 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.