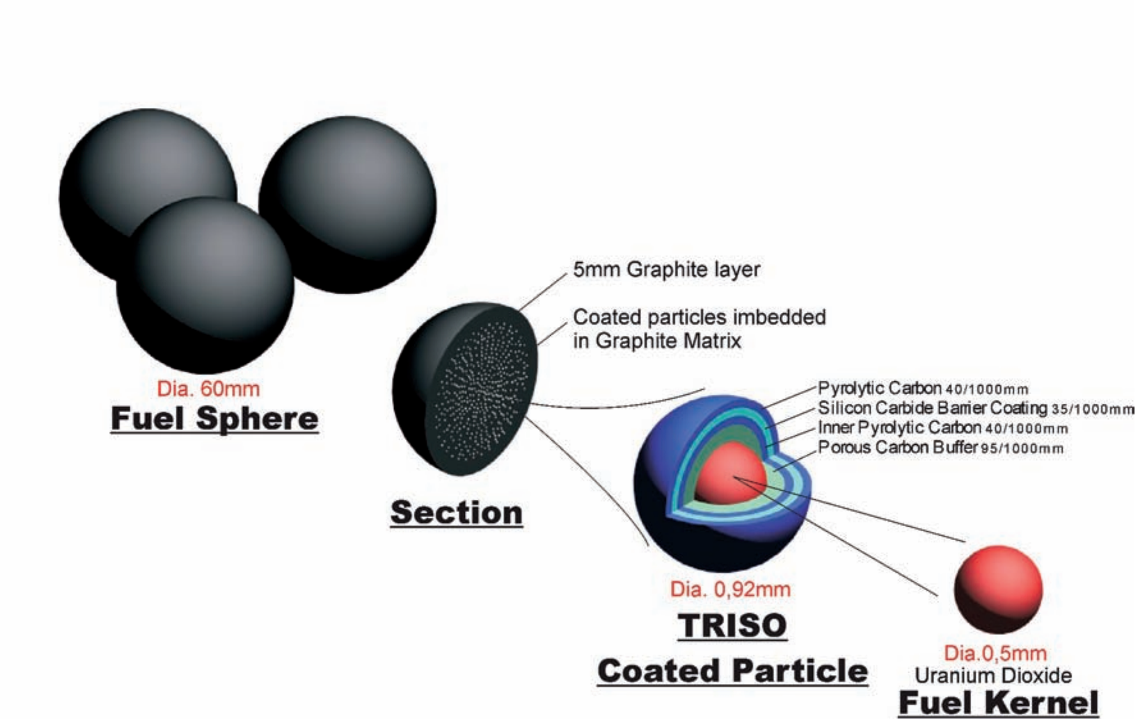
REDEFINING THE NUCLEAR FUTURE

by Tom Ferreira



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It is clean, safe and affordable. It has the potential to form the nucleus of the green energy revolution. It is internationally regarded as the leader of the new generation of High Temperature Nuclear Reactors and it is proudly South African.

Developing out of a desire for energy sustainability, the Pebble Bed Modular Reactor (PBMR) technology defines 21st century energy thinking. Its ability to economically generate electricity and create high value co-products such as hydrogen for the fuel of the future, desalinated water and industrial or residential process heat, not only sets it apart from all previous nuclear reactors, but also from the next generation of energy sources. PBMR's current investors, Eskom, the Industrial Development Corporation and British Nuclear Fuels, share the vision of small, standardised, inherently safe, modular reactors as one of the best carbon-free alternatives for new power generation capacity around the world.

Government support

The project is emphatically supported by the South African Government, who allocated significant funding to the project. Stating intent to eventually build between 20 and 30 pebble bed reactors in South Africa, the Minister of Public Enterprises, Mr Alec Erwin, last year said the mini nuclear reactor will place the country at the forefront of energy technology.

The PBMR is a high temperature gas-cooled reactor with a closed-cycle, gas turbine power conversion system. Although it is not the only gas-cooled high-temperature reactor currently being developed in the world, the South African project is internationally regarded as the leader in the power generation field. Very high efficiency and attractive economics are possible without compromising the high levels of passive safety expected of advanced nuclear designs.

Under development since 1993, the PBMR project entails the building of a demonstration reactor project near Cape Town and a pilot fuel plant near Pretoria. The current schedule is to start construction in 2007 and for the demonstration plant to be completed by 2011. The first commercial PBMR modules are planned for 2013. The PBMR is therefore poised to be the world's first commercial scale advanced reactor built in the new millennium.

The design

The PBMR has a 27 m-high vertical steel reactor pressure vessel that supports a metallic core barrel. The core barrel, in turn, supports the annular pebble fuel core, which is located in the space between a central and outer graphite reflector. Vertical borings in these reflectors are provided for the reactivity control elements.

Two diverse reactivity control systems are provided for shutting the reactor down. One of these systems is control rods in the outer reflector, while the other consists of small absorber spheres that are dropped into borings in the central reflector.

The PBMR uses particles of enriched uranium dioxide coated with silicon carbide and pyrolitic carbon. The particles are encased in graphite to form a fuel sphere or pebble about

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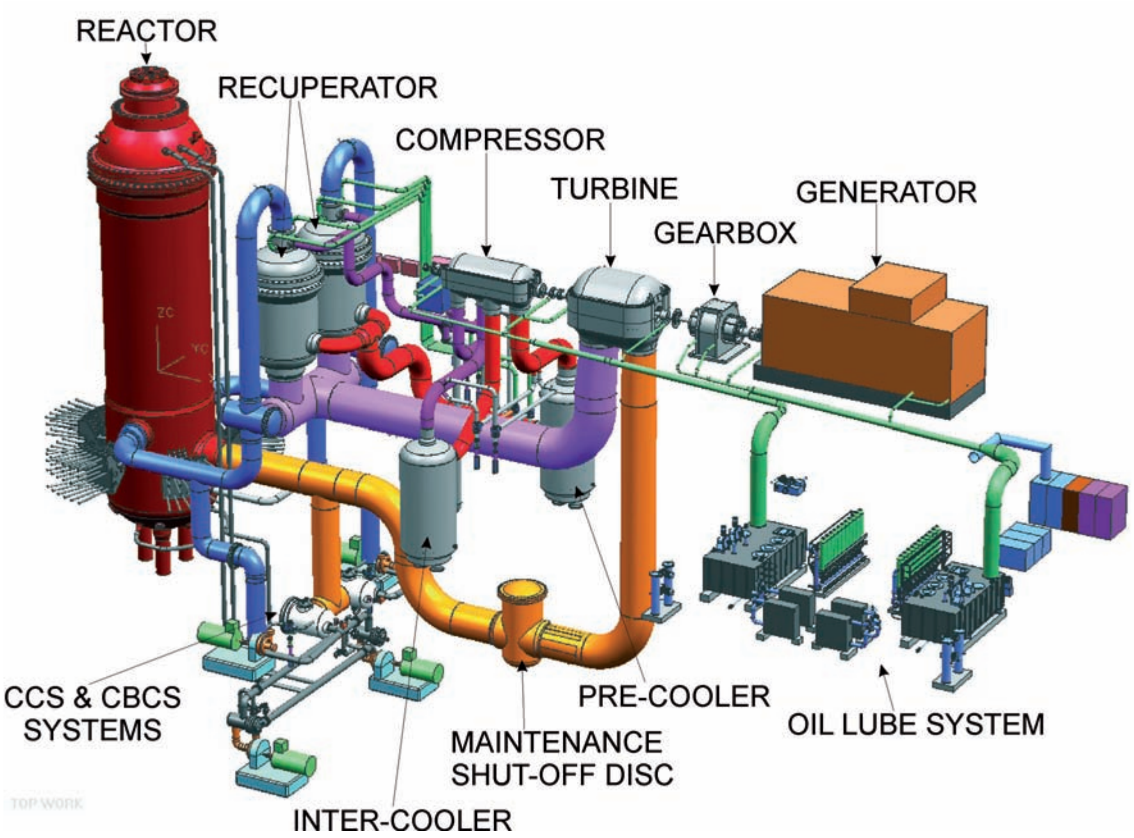

→ *Thermodynamic cycle*

the size of a billiard ball. Helium is used as the coolant and energy transfer medium, to drive a closed cycle gas turbine-compressor and generator system. When fully loaded, the core would contain approximately 450,000 fuel spheres.

How it works
To produce electricity, helium gas at a temperature of about 500°C is inserted at the top of the reactor, and passes among the hot fuel spheres, leaving the bottom of the vessel having been heated to a temperature of about 900°C.

The hot gas then enters the turbine, which is mechanically connected to the generator through a speed-reduction gearbox on one side and the gas compressors on the other side. The coolant leaves the turbine at about 500°C and 2.6 MPa, after which it is cooled, recompressed, reheated and returned to the reactor vessel.

The thermodynamic cycle used is a Brayton cycle with a water-cooled pre- and inter-cooler. A high-efficiency recuperator is used after the power turbine. The helium, cooled in the recuperator, is passed through the pre-cooler, low-pressure compressor, the inter-cooler and high-pressure compressor before being returned through the recuperator to the reactor core. The power taken up by the helium in the core and the power given off in the power turbine are proportional to the helium mass flow rate for the same temperatures in the system. The mass flow rate depends on the pressure, so the power can be adjusted by changing the pressure in the system. The high-pressure and high-temperature operation of the reactor results in a relatively high thermal efficiency.

While a typical light water reactor has a thermal efficiency (electrical power output/ thermal heat input) of approximately 33%, an efficiency of about 41% is anticipated in the basic PBMR design.

Online refuelling is another key feature of the PBMR. Fresh fuel elements are added to the top of the reactor while used fuel is removed at the bottom while the reactor is at power.

The aim is to operate uninterrupted for six years before the reactor is shut down for scheduled maintenance. However, for the demonstration module, a number of interim shutdowns will be required for planned evaluation of component and system performance.

Shutdown will be done by inserting the control rods. Start-up is effected by making the reactor critical, then using nuclear heat-up of the core and circulating the coolant by motoring the turbo-generator set. Heat is then removed by the pre- and inter-cooler. At a specified temperature, the cycle becomes self-sustaining.

→ PTO

→ *Scale model of the PMBR system earmarked for Koeberg, near Cape Town*

Safety systems
The passive safety systems of the PBMR are designed to make it "meltdown proof". The physical characteristics of the reactor are such that it shuts itself down, without any engineered safety systems, in any imaginable accident scenario. The PBMR system has a self-stabilising temperature effect: if the temperature of the reactor core should heat up, this slows down the neutron production, because of the large amount of U-238 in the fuel particles, which captures the neutrons without fissioning. The spent fuel from the PBMR also has built-in safety features. Because it is encapsulated in several coatings, including silicon carbide, the radioactive fission products remaining in the spent fuel are fully contained within the fuel kernels.

The reactor core concept is based on the well-tried and proven German AVR power plant, which ran for 21 years until 1986. This safe design was proven during a public and filmed plant safety test, when the flow of coolant through the reactor core was stopped and the control rods were left withdrawn just as if the plant was in normal power generation mode.

It was demonstrated that the reactor core shut itself down inherently within a few minutes. It was subsequently proven that there was no deterioration over and above the normal design failure fraction of the nuclear fuel. This proved that a reactor core meltdown was not possible, and that an inherently safe nuclear reactor design had been achieved.

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Further reading

Rousseau, P.G., Greyvenstein, G.P., 2004, "Changing the Face of Nuclear Power via the innovative Pebble Bed Modular Reactor," Proceedings of Power Generation World, 16-17 March, Gallagher Estate, Midrand, South Africa.