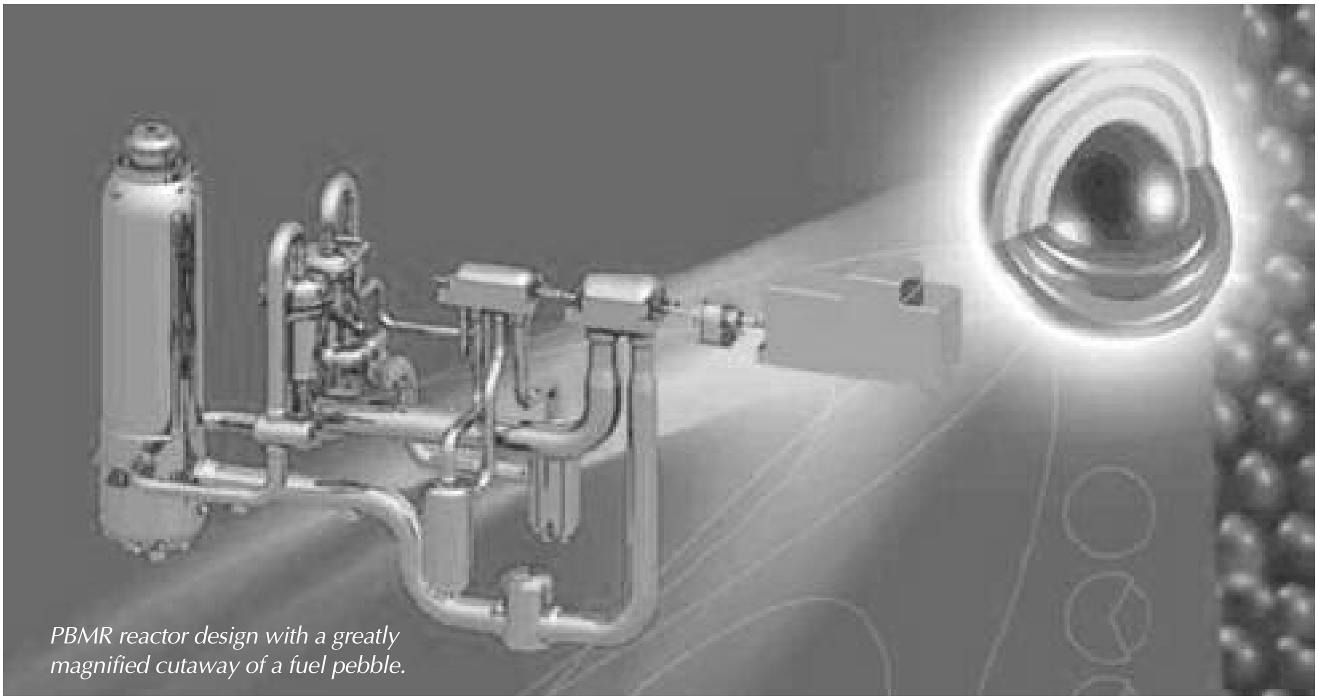
South Africa's PBMR:



PBMR reactor design with a greatly magnified cutaway of a fuel pebble.

World's Most Versatile Nuclear System

Jonathan Tennenbaum

A report on an international conference in London to discuss the fantastic economic potential worldwide of South Africa's Pebble Bed Nuclear Reactor.

Next year the Republic of South Africa will begin on-site construction of the first Pebble Bed Modular Reactor (PBMR)—a revolutionary nuclear power source which South Africa's Minister of Public Enterprises calls "the perfect nuclear technology for Africa and the developing countries."

With the PBMR, South Africa has taken the leading edge in fourth-generation nuclear technology, combining extraordinary simplicity, robustness, and "inherent safety" with the capability to produce high-temperature heat for the production of hydrogen-based fuels and other industrial processes, as well as cheap electricity.

The PBMR is a leading exemplar of the High Temperature Reactor (HTR) technology, which Lyndon LaRouche and his collaborators have long identified, in the context of development programs (for example, the Eurasian Land Bridge and the recent campaign for re-industrialization of the United States), as the key "workhorse" power system for global economic reconstruction and growth in the coming period.

The PBMR project builds upon a long historical development, which began in the 1950s, when the German nuclear physicist Prof. Rudolf Schulten began to think about creating a 100 percent "inherently safe" nuclear power source, which could be deployed all over the world, including in developing countries, as an efficient industrial heat source and for the generation of electricity. A key to Schulten's ingenious solution was to encapsulate small particles of fuel within ceramic materials that could withstand high temperatures, in such a way that the radioactive fission products remained permanently trapped in situ, where they are created.

At the same time, Schulten tailored the choice of fuel, helium coolant, and reactor construction, to ensure a uniquely favorable nuclear reaction behavior, which excludes the danger of a runaway chain reaction, and permits routine operation at temperatures up to 1,000°C. Schulten's concept was tried and proven in over 20 years' operation of the AVR 30-megawatt test reactor at the nuclear research center in Jülich, Germany.

Geraldine Bennett/PBMR

A somewhat different reactor type, based on the same basic ceramic-coated particle principle, was pursued by General Atomics in the United States. The General Atomics GT-MHR uses tiny fuel particles, but places them in small rods that are stacked into columns, not as loose pebbles.

Unfortunately, after brief operation of a larger, 300-MW HTR version, all work on Schulten's concept was dropped in Germany, as part of the politically motivated, virtual shutdown of that nation's once-proud nuclear sector. The U.S. HTR work did not fare much better, and it is only thanks to three countries, South Africa, China, and Japan, that this technology has been kept alive.

Today, HTR test reactors are operating in China and Japan—the first based on Schulten's essential design, the second closer to the U.S. design. China has recently announced that it will move to large-scale production of commercial HTR units as part of its nuclear energy program. General Atomics has a joint project with Russia to build a GT-MHR that will burn weapons plutonium. However, by far the most advanced project, one which promises to deliver a crucial, long-delayed breakthrough for Schulten's original concept of a universally applicable nuclear energy, is South Africa's PBMR.

The International PBMR Conference

On Jan. 30, 2005, Britain's Nuclear Industry Association sponsored an international conference devoted entirely to the PBMR, and attended by some 200 industrialists, nuclear experts, and political representatives from South Africa, the United Kingdom, the United States, Japan, France, Germany, Spain, and Switzerland. The conference, addressed by leaders of the South African program, as well as that nation's Minister of Public Enterprises, served both as a first full-fledged public presentation of the entire PBMR program in Europe, and as a follow-up meeting of international suppliers and investors, to an August meeting in South Africa.

The account of the conference presented here speaks for itself, and should enable the reader to become familiar with leading features of the technology and its potential importance. I shall not comment on the geostrategic implications of this technology not being produced in Germany (its country of origin) nor in the United States, but in a nation of the British Commonwealth. This should be a wake-up call to all, that the era of suppression and stagnation of nuclear energy development has drawn to an end.

I was also impressed by the display of national pride and optimism on the part of the representatives from South Africa, and also of a certain basic competence in industrial and economic policy, which is a highly refreshing contrast to the sheer insanity that still dominates policy-making in the United States and Europe. If there was a certain, understandable amount of "hype" in the PBMR presentations, it was a pleasant one.

Greeting the conference, Robert Hawley, former Chief Executive of British Energy, emphasized two points. First, the major technological advances embodied in the PBMR; its sim-

Geraldine Bennett/PBMR

John Ritch, head of the World Energy Association (left) and Thulane Gcabashe, CEO of Eskom, at the PBMR conference.

plicity, speed of design, and rapid construction. The 165-megawatt-electric modules are very appropriate for developing countries, which lack extensive electricity grids. Hawley noted also the massive support given to the project by the South African government and the state-owned electricity company, Eskom, as well as the wise decision by both to draw in world-renowned industries, such as Mitsubishi Heavy Machinery, in supplying certain key components of the reactor, alongside the major role of South Africa's own domestic industry.

"Tears of frustration come to my eyes when I compare the attitude of the UK government to that of South Africa," Hawley said.

Dr. Alistair Ruiters, the chairman of the PBMR project, emphasized the fruits of "14 years of hard work," starting with the 1990 decision by Eskom to devote a small budget to examining the potential of the original German technology. A crucial turning-point came in 1994-1995, when South Africa voluntarily abandoned its originally military nuclear program and redeployed its manpower and resources into the PBMR project. Now the project is engaging suppliers spanning the globe, guaranteeing the commercial viability of a new path for nuclear energy. At the same time, the PBMR will constitute a major contribution by South Africa to improving the lives of people in Africa.

'Join Us on an Exciting Journey'

Jaco Kriek, CEO of PBMR, showed an upbeat video on the South African project, entitled "Expand your mind." The basic message was well presented: In the context of the need to upgrade an infrastructure that is already strained by South Africa's rapid economic growth, and at the same time to recapitalize the country's heavy industry and scientific-technological capability, South Africa has decided to make itself into a "global center for nuclear excellence," placing export of standardized nuclear reactor modules at the forefront of a strategy to cement the country's role as a major exporter of capital equipment. At least 12 countries are currently interested in purchasing PBMRs.

Kriek noted that "energy is a hot topic," and that the PBMR is "South Africa's unique contribution to the global challenge" of meeting mankind's power needs, not only for electricity, but also for transport and industry. He pointed to the decisive importance of this technology for Africa in particular—the giant continent that shows up nearly totally dark, from lack of electric power, in the satellite image of the world at night. Power is the key to kick-starting the African economies.

The first pilot PBMR will be completed in 2011, to be followed by commercial mass production of at least 30 commercial modules for domestic use and export. Eventually, hundreds could be produced. At present, the approximate timetable looks something like this: First commercial units produced by 2014; production rising to 6 modules a year by 2015; at least 24 modules eventually to be delivered to the electric utility, Eskom. It could go even faster.

Key components of the technical infrastructure already being set up for the PBMR effort include a pilot fuel-element plant at Palindaba, the HTR helium test facility, and the HTTF, Heat Transfer Test Facility. These, Kriek emphasized, are world-class test facilities that will offer their services worldwide, in addition to supporting the PBMR program itself.

Kriek emphasized also PBMR's commitment to leverage the project toward creating new jobs in South Africa. Besides beefing up the country's high-value capital goods export potential, PBMR is encouraging international suppliers to the project to localize parts of the production in South Africa itself. Production of PBMR modules will have a local content of about 60 percent, while international partners will provide the remaining 40 percent.

The electricity-producing version of the PBMR already has a large customer in the South African power company, Eskom, which is committed to purchasing a total of at least 4,000 megawatts-electric of PBMR capacity, as the spearhead of its modernizing and expansion program for power production. However, in the future, the process-heat application may be even more interesting, not least of all for hydrogen production. PBMR is already planning to construct a second demonstration plant that will demonstrate the process-heat capability.

PBMR is classified as a "National Strategic Project," but at the same time it involves a remarkable international cooperation. The list of PBMR's international suppliers includes Mitsubishi Heavy Industries (MHI), which will provide the crucial helium turbine systems for the PBMR direct-cycle electricity production, as well as British Nuclear Fuels/ Westinghouse, Germany's Nukem and Uhde, SGL Carbon, Spain's steel supplier ENSA, Canada's SNC-Lavalin, Murray Roberts, and many more.

Africa's lack of electricity is striking in this satellite view of the continent at night, where electric lighting shows up as white dots. Although the continent has 12 percent of the world's population, it accounts for only 2 percent of the world's energy consumption.

Africa Needs Power!

Most interesting was the presentation by the CEO of South Africa's state-owned national electricity company Eskom, Thulane Gcabashe. Eskom is currently the ninth largest electrical utility in the world, he noted, producing 95 percent of South Africa's electricity and 50 percent of the entire electricity consumed on the continent of Africa.

Gcabashe showed once again the impressive satellite mosaic of the Earth at night, pointing to the fact that Africa—very literally the dark continent in the picture—accounts for 12 percent of the world's population, but only 2 percent of the world's energy consumption. On the other hand, Africa has extremely plentiful natural resources for energy generation, in terms of hydro, coal, and uranium, which could be used. Gcabashe made clear that Eskom's strategy takes into consideration not merely South Africa's needs, but the requirements of the entire African continent, home now to 700 million people.

For the last 10 years, despite a massive electrification campaign in South Africa, Eskom has maintained an excess of power-generation capacity. That excess is rapidly shrinking, however, and the country is now only one year away from the point at which a rapidly growing demand for electricity will overtake presently installed capacity. As an immediate measure, Eskom added an additional 3,600 megawatts-electric of capacity in 2005, by bringing several power plants back on line that had been mothballed since the 1980s. Further capacity of 5,304 megawatts-electric is being added, by upgrading the performance of existing units. But in the medium term, it is only by mounting a massive program of new plant construction, that South Africa will be able to keep up with the skyrocketing demand.

After taking into account all available options, Eskom decided to choose nuclear energy, in the form of the PBMR, as the key vehicle to meet this challenge. The crucial areas of application are the rapidly growing coastal regions in the Cape and Kwa-Zulu regions of South Africa, which are located far from the country's coal-producing area.

After a detailed feasibility study in 2002, Eskom made its initial commitment to install a minimum of 1,100 megawatts-electric of nuclear PBMR capacity, beginning with the "Strategic National Demonstration Project" that goes into construction next year. Beyond this, Eskom is looking at a total of at least 4,000 megawatts-electric of PBMRs. Gcabashe's projections suggest that in the longer term, some 10,000 megawatts-electric of additional capacity will be needed, corresponding to about 60 of the standardized PBMR modular units.

How to Build a Stable Energy System

South Africa's Minister of Public Enterprises, Alec Erwin, elaborated on the thinking process behind the strategic decision by the South African government to go for its ambitious PBMR-based nuclear energy program. Why would a country like South Africa opt for such a policy course? For a long time, energy was not at the forefront of the government's agenda. But after 10 years of rapid economic growth, Erwin said, we had to really start thinking about the problem: How do you get a stable energy system?

Because there are no powerful energy suppliers among the neighboring countries, the emphasis would have to be on South Africa's own production. The nature of South Africa's economy dictated the need to diversify, and at the same time provide for long-term stability of energy production and energy costs.

The South African government decided to keep the electricity company Eskom in state hands, giving it the ability to raise capital and to carry out sophisticated projects. South Africa is one of the world's largest uranium producers. In addition, South Africa possesses an entire complex of facilities previously connected to the military nuclear program. Going with the PBMR project was not an easy decision, but the technology seemed to fit so well, particularly in view of its potential impact on the industrial development of South Africa's economy.

Further, the favorable fiscal situation gave the government the possibility to support big projects. The worldwide community of scientists and nuclear technology suppliers provided enthusiastic support, giving us the sense that we were not alone, Erwin said. Thus, the PBMR has the character of a global project.

Erwin emphasized the unique advantages of the PBMR for the developing countries in Africa and around the world (see accompanying interview). He noted the major interest from many countries with whom South Africa is in discussion, including Brazil, India, and China. China, which is already operating a small test reactor based on the same basic pebble-bed technology, has signed a memorandum of understanding for cooperation with South Africa.

There is a certain amount of opposition to nuclear energy in the country, Erwin noted, but most of it is coming through the global non-governmental organizations, NGOs. The debate in South Africa is more reasonable than it has been in the so-called developed world, and in reality, the so-called renewables like wind provide no serious alternative to nuclear technology, he said.

All in all, Erwin concluded, "this is an important time for nuclear energy as a whole" and a "wonderful confluence of events" that placed South Africa in a position to play the leading role in realizing the revolutionary PBMR technology.

Nuclear Modules in Six-Packs

A particularly enthusiastic note was added from the United States by Regis Matzie, Chief Technical Officer of Westinghouse Electric Corporation. Matzie called the PBMR project a "model of international cooperation," noting that in addition to the international suppliers already mentioned, Russia was also playing an important supporting role by providing testing facilities for the PBMR fuel elements.

Matzie had high praise for the South African effort and the full-hearted support given to it by the government. Already 4.3 million man-hours have gone into the design, and world-class test facilities. South Africa's Northwest University has carried out extensive work on the Brayton-cycle helium cooling system, and the helium test facility with its 40-meter tower is nearly completed.

"There are no serious technical issues left," Matzie said, noting that the PBMR construction will incorporate the proven fuel element design and operating experience of the AVR and THTR systems in Germany, as well as standardized materials from the conventional light water reactor industry.

What about the future market? When we speak of the PBMR being able to supply a "niche" for plants with total power of 700 megawatts-electric or lower, "that niche is pretty big." It includes much of the developing sector of the world economy. Moreover, the possibility of combining many standardized PMBR modules in "four-packs," "six-packs," and "eight-packs" (so-called "multi-modular design") could make them building-blocks for commercial plants worldwide.

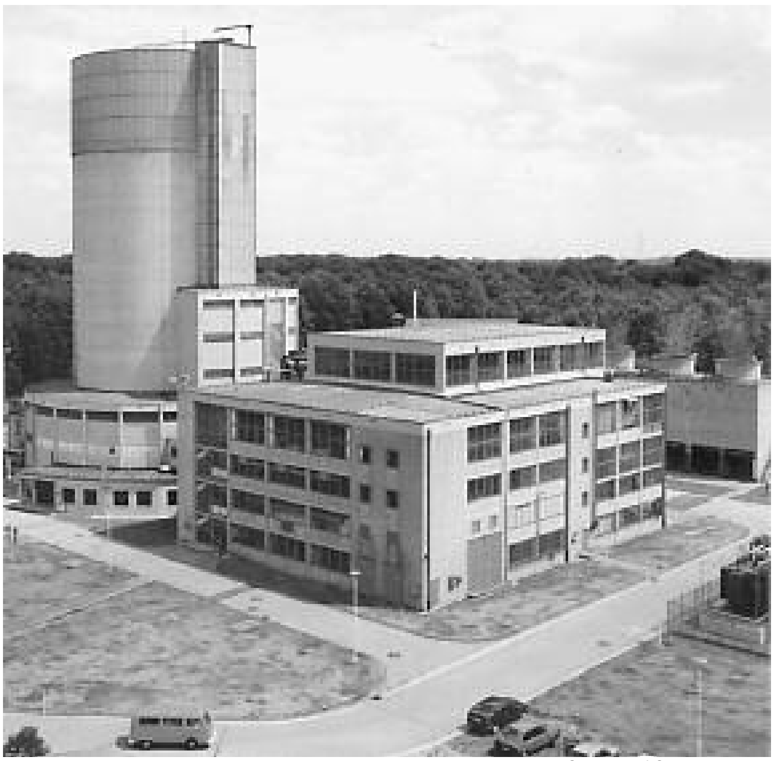
But the process heat applications, Matzie said, are potentially even larger. Of the U.S. energy consumption, for example, about one-third is electricity, but two-thirds is transportation and heat applications. The PBMR will be key to a future hydrogen economy.

Europe's Energy Challenge

Dr. Sue Ion, technical director of the company British Nuclear Fuels (BNFL), which has been a major partner of the South African project, spoke about "A European perspective on nuclear energy and the PBMR."

"Could there be a renaissance of nuclear energy in the UK and Europe?" Dr. Ion asked. The European Union is the largest energy importer in the world, and the import quota could increase from 50 percent to as much as 70 percent in the coming decades.

The stability and security of energy supplies is in serious question. She said the United Kingdom is facing a gradual depletion of the North Sea oil and gas reserves. The reserve storage of natural gas in the U.K. is a mere 14 days. Europe currently has 685 gigawatts-electric of electric-generating capaci-



Courtesy of General Atomics

The predecessor of the PBMR, the AVR experimental pebble bed reactor in Jülich, Germany, came on line in 1967 and operated successfully for 22 years. It demonstrated many safety effects of the high-temperature reactor. One test showed that in a sudden total shutdown, the plant cools down and the fuel remains intact.

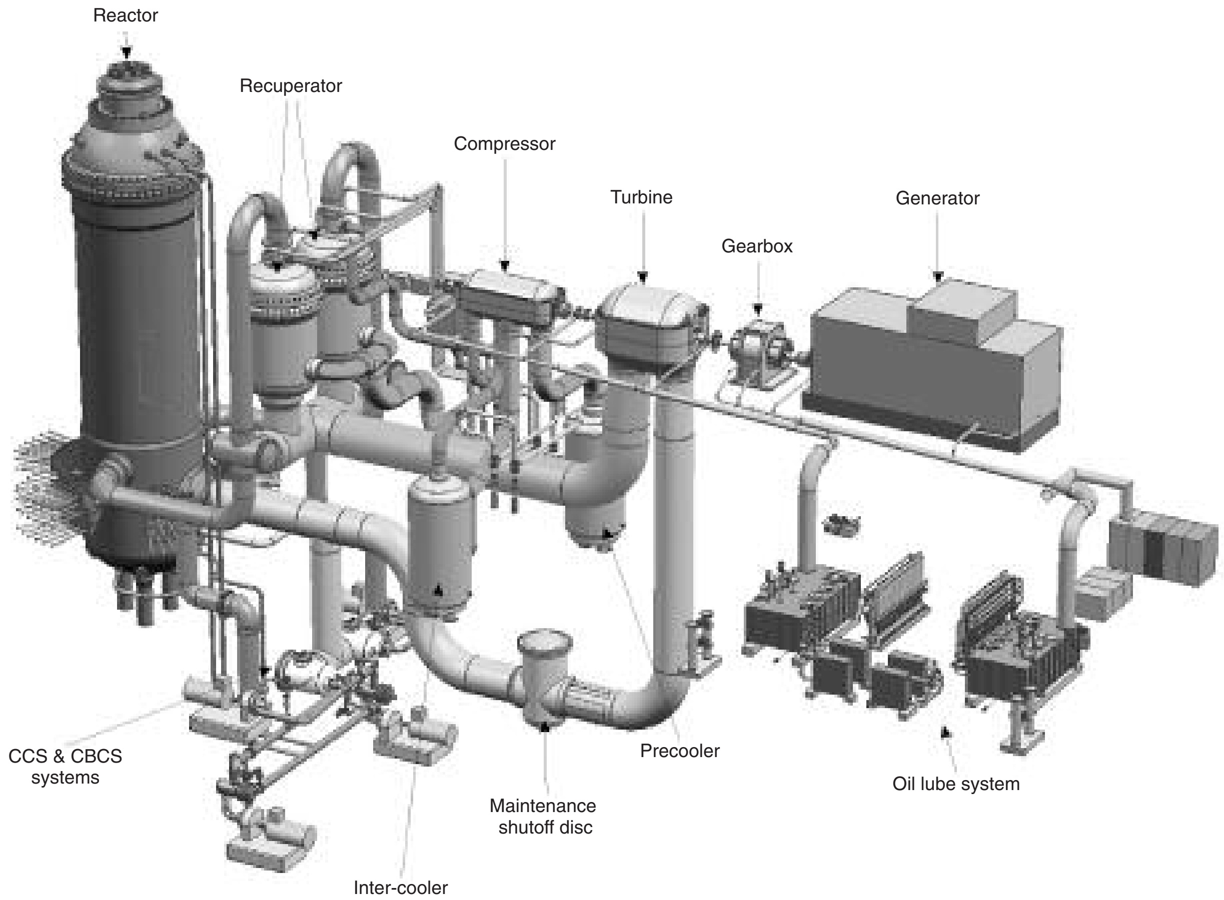


Figure 1
PBMR REACTOR DESIGN
This schematic drawing shows the main power and support systems for the Pebble Bed Modular Reactor.

ty, which must be expanded to more than 900 gigawatts-electric by the year 2020. At the same time, much of the existing fleet of power plants is aging and must be replaced, many already in the coming 10- to 15-year period. The present state of the electricity distribution system in Europe, including the limited capacity for interconnections, leaves no alternative to a major push for new plant construction.

In this context, European countries are having to look very seriously at the role of nuclear energy. France is set to begin major replacements of its nuclear reactor fleet. In the U.K., influential "environmentalists" such as Gaia proponent James Lovelock and Hugh Montefiore have come out in favor of nuclear energy, and recent studies of the British Institute of Civil Engineers have underlined the weakness of wind power and other so-called alternative technologies. Finland is building a new nuclear power plant, and in Switzerland the population voted in a referendum to keep the nuclear option open, Ion said.

In addition to the electricity-generation problem, we must do something about the energy requirements of the transport sector, which accounts for nearly 56 percent of energy use in the European Union, she said. Here the pebble-bed technology, as a heat source for hydrogen and other synthetic fuels, gives us "the first real breakthrough."

"The PBMR is a fantastic technology," Ion said, and would be ideal for a number of locations in Great Britain itself, where smaller units are most suitable. In addition, the U.K. could exploit its extensive experience with gas-cooled reactor technology. "I hope I live to see the first PBMR switched on here," she concluded.

Building on a Long History

Dieter Matzner, the general manager of the Power Plant Division of PBMR, described the historical process leading to South Africa's taking up the High Temperature Reactor technology originally developed in Germany. A key turning-point, ironically, was the German government's own decision in 1990 to discontinue all work on its HTR. This crazy decision came just months after the basic HTR modular reactor design, which provided the take-off point for the later PBMR development, had been officially licensed by Germany's Nuclear Safety Commission.

The inventor of the HTR, Prof. Rudolf Schulten, died suddenly in April 1995, just two weeks after having signed a crucial agreement with South Africa for the transfer of the HTR technology. South Africa's early interest in the HTR was heightened by realization of the implications of large-scale desalination for a largely arid country, as well as the large distances separating the country's huge coal fields from most of its population centers.

Matzner emphasized the uniqueness of the safety features of the PBMR, underscoring the difference between so-called "passive" safety incorporated into the latest-generation light water reactor designs of the European EPR (European Pressurized Reactor) and the Westinghouse AP-1000 on the one side, and the "inherent safety" of the PBMR on the other. A crucial difference is that in the PBMR a meltdown of the reactor core is not only extremely improbable—as in the EPR and AP-1000—but literally impossible.

In addition, Matzner said, the same design for the spherical fuel elements, based on encapsuling tiny particles of fissile fuel in high-temperature ceramic coatings, which is key to the inherent safety features of the PBMR, also provides an unrivaled packaging system for nuclear waste. The ceramic materials employed, remain stable and corrosion-proof for millions of years. In the context of the reactor fuel, the ceramic encapsulation prevents significant release of radioactive substances up to temperatures of 1,800°C or more, far above the maximum temperatures attained in the reactor, even in the "worst-case" accident scenarios.

Among other additional advantages of the PBMR design (see accompanying interview), Matzner mentioned the uniquely favorable dynamic behavior of the reactor, which is linked to its strongly negative-temperature coefficient. This means, that when the reactor temperature increases beyond a certain point, the efficiency of the fission reactions decreases rapidly, leading to the chain reaction "shutting off" by itself. This not only excludes the possibility of a dangerous runaway chain reaction, with overheating and other negative effects, but also means that the reactor's power output can be regulated essentially by the rate of cooling that the cooling system provides. The faster we cool it, the more power the reactor supplies. And the less we cool it, the less heat the reactor produces, as the fission reactions slow down automatically.

Japanese Know-how

A very important feature of the South African PBMR system, is the decision to use a "direct-cycle" helium turbine to power the generator for electricity production. Virtually all existing nuclear power stations and conventional electricity plants employ steam turbines for their power generation. The very high (900°C) operating temperature of the PBMR, the extremely low level of release of radioactivity from the fuel, and the characteristics of the coolant itself—inert helium gas—provide the possibility of operating a gas turbine at very high efficiencies, while at the same time avoiding the bulky and complex heat exchangers of conventional light water nuclear power plants.

It also affords great ease of repairs and maintenance in a low-radioactivity environment.

The helium turbine of the PBMR has some similarity to a jet engine; it is simpler, relatively much smaller, and has a higher power density than the steam turbines of conventional power plants.

For this high-technology item, the South Africans decided to bring in the experience and expertise of Japan's famous Mitsubishi Heavy Industries (MHI), one of the world's major producers of power turbines, including gas turbines for natural gas-based power plants. Mitsubishi was represented on the conference panel by Yoshiaki Tsukuda, general manager of MHI's Takasago Machinery Works.

On the Way to a Hydrogen-Based World Economy

Willem Kriel, manager of U.S. Programs for the PBMR company, gave an exciting overview of the potential of the HTR-PBMR system as a source of high-temperature heat for industrial processes—applications that promise to generate an even greater economic impact, than that of electricity generation. These include large-scale hydrogen production; synthetic natural gas and other liquid and gaseous fuels from coal, oil, or other carbon sources; process heat for refineries and other chemical plants; heat and steam for recovery of heavy oil and other resources; large-scale desalination, and so on.

Kriel spoke of a "new frontier" opening up, symptomized by the suddenly emerging interest on the part of fossil-based fuel companies, to explore the possibility of applying nuclear energy to "leverage" existing hydrocarbon reserves. The PBMR is presently the only existing technology, apart from combustion of fossil fuels, which can economically provide large amounts of heat in the range of 900°C. It is also the only carbon-dioxide-free source. Applying this heat to endothermic steps in the conversion of coal and oil to synthetic fuels, and to the thermochemical production of hydrogen, which is an important intermediate for synthetic fuels, will make it possible, in effect, to "stretch" existing fossil fuel reserves by a very considerable factor.

The PBMR could leverage gas by 30 percent, and coal by 100 percent, while at the same time providing the basis for economically exploiting vast amounts of oil sands existing in various locations. The recoverable hydrocarbons from the oil sands in Canada and Venezuela alone, would exceed in equivalent the entire oil reserves of Saudi Arabia, Kriel said.

In this context, "he who hesitates will be last," Kriel declared, pointing to five conditions defining a unique "window of opportunity" for the introduction of nuclear process heat into the world's energy market. To succeed, any proposed technology: (1) must come soon; (2) must be safe, in order to be located close to process heat-consuming plants; (3) must be economical; (4) must have the right size, ideally in the range of 400-500 megawatts-thermal; and (5) must produce the right temperatures, in the range of 800-1,000°C. The PBMR modules fit exactly these requirements, with no serious competition on the scene.

Kriel praised the "revolutionary" pioneering work of Prof. Rudolf Schulten and his collaborators in Germany during the 1960s, on applications of HTR process heat. It was a pity, he said, that political circumstances prevented that work from coming to full fruition. But with the PBMR, "nuclear energy has finally broken the shackles of only being able to make electricity."

Parallel with the effort to complete the demonstration PBMR for electricity production, work is now going on to prepare for a

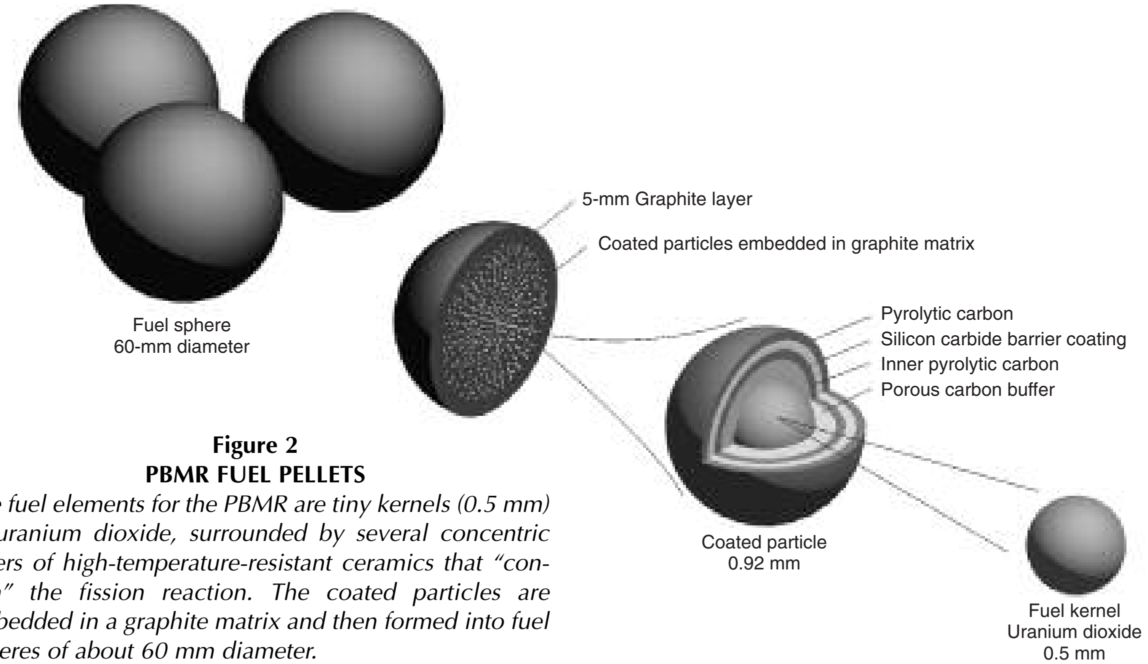


Figure 2
PBMR FUEL PELLETS
The fuel elements for the PBMR are tiny kernels (0.5 mm) of uranium dioxide, surrounded by several concentric layers of high-temperature-resistant ceramics that "contain" the fission reaction. The coated particles are embedded in a graphite matrix and then formed into fuel spheres of about 60 mm diameter.

pilot plant for process-heat application, in discussion with a variety of potential industrial users, including the petrochemical industry. Kriel spoke of "three to four near-term applications" which could potentially involve "large numbers" of PBMR modules. The modules in question would be "dedicated" to heat production, and would not need the elaborate heat-to-electricity conversion system of the electricity-producing PBMR.

At the same time, work is proceeding on addressing the details of matching the output heat production of the reactor, to the different characteristics of the consuming processing plants. The first demonstration facility will involve a consortium of industrial clients. The required heat-exchanger and chemical reactor technology can be developed and tested in parallel, separately from the nuclear reactor, using other heat sources, Kriel said.

There are "three to four possible projects" in the near-term, Kriel stated, and the priority now is to push ahead with planning, complete technical development in 2007-2012, and have pilot plants running by 2015, which would be the date of "commercial roll-out" of process-heat PBMRs.

Educating a Young African Labor Force

Thabang Makubire, general manager of the Fuel Plant Division of PBMR, took his audience through the fascinating process of production of the spherical fuel elements—the "pebbles"—which constitute the heart of the PBMR technology. First, microspheres of enriched uranium-containing solution are formed in special nozzles, and then jelled and calcinated at high temperatures, producing tiny "kernels" of uranium dioxide of 0.5 millimeter diameter. These are then run through a Chemical Vapor Disposition furnace at temperatures of 1,000°C, where they are coated with successive layers of silicon carbide ceramic and pyrolytic carbon.

The result is a hermetically sealed, coated particle of a little less than 1 millimeter diameter, which is extremely hard and high-temperature resistant. This multiple coating constitutes a practically fail-safe barrier to the release of the radioactive fission products generated in the uranium kernel as a result of the nuclear reactions. Approximately 15,000 of these coated particles are then mixed with graphite powder and resin, and pressed into a sphere of about 60 millimeters diameter, covered with an additional layer of

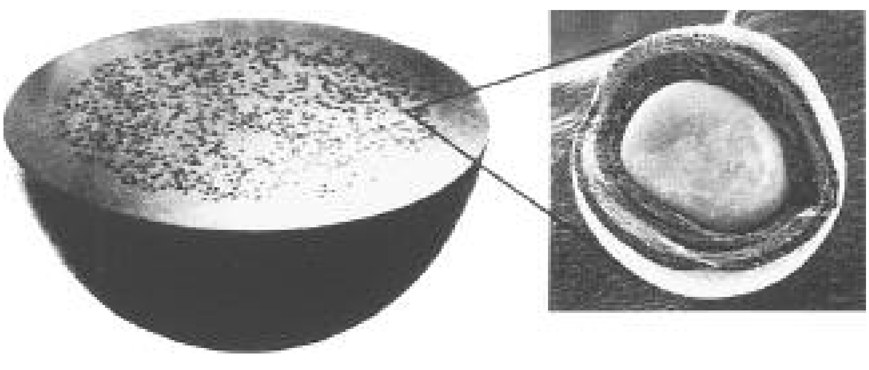


Figure 3
CROSS SECTION VIEW OF FUEL PEBBLE
A cross section of a PBMR fuel pebble, with a cutaway view of a coated fuel particle.

pure carbon (graphite) as a "buffer," and finally sintered, annealed, and machined to extreme hardness.

The core of the PBMR module—the pebble bed—consists of 450,000 to 500,000 of these tennis-ball-size fuel elements. In the course of operation, the pile of fuel elements is constantly renewed and recycled, as fuel balls are gradually introduced into the annular-shaped core from the top, and withdrawn from the bottom. Each fuel ball makes about six passes through the core, with the degree of "burn-up" measured in between.

Because this is a continuous fueling process, it is no longer necessary to shut down the reactor at frequent (18-20 month) intervals for refueling, as is necessary for conventional nuclear power stations. A pilot fuel-element production plant is already in operation, and has produced a small lot of 81 fuel balls, which are now being tested in Russia under reactor conditions.

A full-scale fuel-element plant is scheduled to be commissioned in 2008-2009. Meanwhile, the South Africans are using the pilot plant to train technical staff for the commercial plant. This, as Makubire emphasized, is part of a broader policy of PBMR and the South African government, to use the nuclear energy program as a driver for labor-force development, focussing on so-called "localization" of production, and drawing into the process young Africans, who are the key to the country's future.

Crucial Role of Government Institutions

The conference drew to a close with a presentation by Mukesh Bhavan, executive vice president of South Africa's state-owned, but self-financed Industrial Development Corporation (IDC), and with final remarks by PBMR CEO Jaco Kriek.

Bhavan noted that the IDC's present role in the financing of the PBMR project continues a very long tradition of support for government-identified strategic projects directed toward developing South Africa's industry. A key success story was the creation of SASOL, the chemical giant which leads the world in the production of gasoline and other hydrocarbon products based on coal. At present, SASOL's coal liquification plants produce about a third of South Africa's gasoline and diesel consumption. The technology developed in the context of SASOL has had "phenomenal spin-offs" for the country's industry and economy generally, Bhavan said, "and we have the same vision for the PBMR." The IDC is increasingly engaged, also, in financing industrial projects in other African countries.

As a National Strategic Project of the South African government, the PBMR seems indeed to be on the road to success—reminding us of the kinds of things the United States and some other countries used to do so well, before the insane, radical "free market" ideology took over. Time for rethinking?

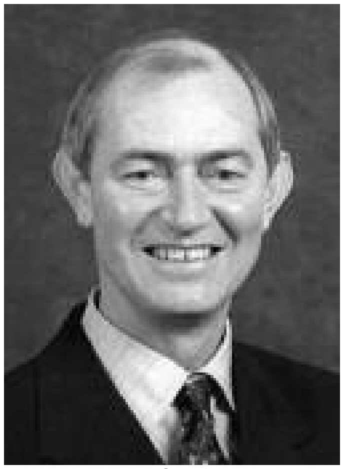
Meanwhile, South Africa is on the countdown, with officially 2,096 days to go, for its first pebble bed modular reactor to go online.

Dr. Jonathan Tennenbaum, based in Berlin, heads the Fusion Energy Foundation in Europe and is a scientific advisor to Lyndon LaRouche. His report also appeared in the Feb. 10, 2006 issue of EIR. *He can be reached at tennenbaum@debitel.net.*

INTERVIEW: ALEC ERWIN

PBMR Is 'Perfect' for Africa's Development

Erwin is Minister of Public Enterprises of the Republic of South Africa. He was interviewed by Jonathan Tennenbaum on Jan. 30 at the London conference on the PBMR.


Geraldine Bennett/PBMR

Question: Somebody might exclaim, "my goodness, Africa is starting at such a low level and now you are bringing in such an advanced technology like nuclear. Isn't this a complete mismatch?" What would you say to that?

Well, I think that would be a naive view. If you look at the South African economy itself, it ranks as 25th largest in the world. It is an increasingly sophisticated manufacturing exporter. More than 60% of our exports are manufactured products. We are now a significant exporter of automotives and motor cars, and we make significant amount of avionic and aerospace equipment.

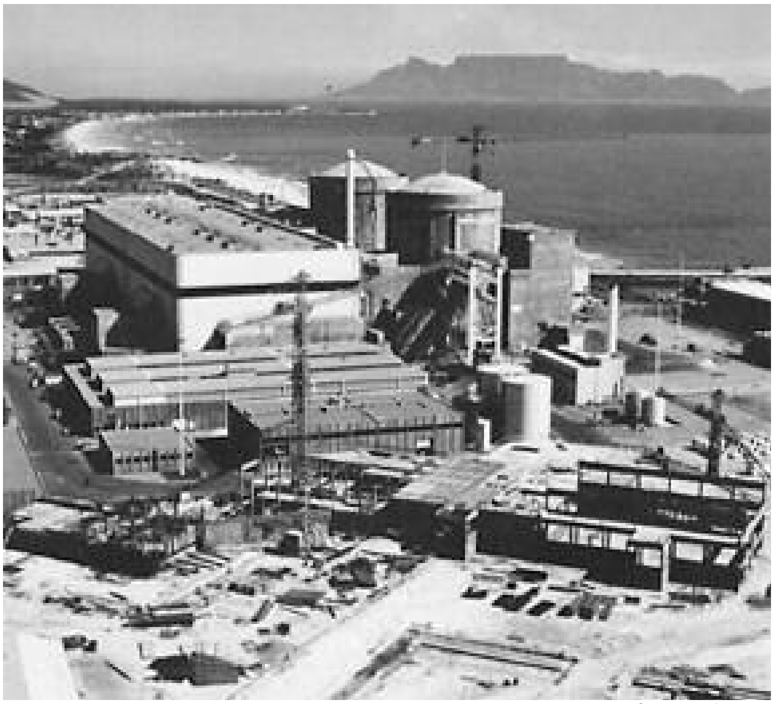
In South Africa you already have an industrial base that is strong, and if you look at Africa's needs, which are the exploitation of its mineral resources, increasing its agricultural potential, and so on, it needs energy to do that. So, in fact, the contrary is true; this is the perfect technology for Africa—and not just for Africa, but for many developing countries. This is wonderful: You can take a plant, you can put it close to your energy needs, you can put it close to the surrounding town, and you don't have to put in gigantic grids, because the management of grids across an extensive terrain is a difficult process. In Africa only South Africa has that capacity.

So I think this is actually one of the reasons we backed it so strongly: It is the most appropriate technology for the developing countries. It will allow Africa to exploit its massive potential.

Question: Many think of nuclear as mainly a black box, only concerned with obtaining electricity as cheaply as possible. But what about the effect of having a nuclear energy program on the economy, on the labor force, and so on. How do you look at that?

I am glad you raised that. There are three components which went into our strategic decision-making. Some relate to South Africa specifically; some are relevant for the rest of Africa.

First, we do have an industrial base. And this helps us to rebuild many of the heavier industrial componentry of our base, which were linked with the mining industry. Second, it allows



Courtesy of Eskom

South Africa's Koeberg Nuclear Power Plant has two conventional 922-MW reactors that have been in commercial operation since 1984 and 1985. Nuclear now supplies about 4.5 percent of South Africa's electricity.

us to enhance our scientific and technological capacity; it's a very useful component of that.

But third, the heat uses we can devise here are very very important. A very basic one for us is the prospect of desalination of water, which is very exciting for us. And we will be working with our own very big company, SASOL, which is a very advanced chemical company, pioneering gas-to-liquid technologies and coal-to-liquid technologies. We are going to do pilot plants with them.

So you have the spin-off effects from the point of view of your industrial base, your science and technology base, but also the heat-transfer uses that will have an important industrial effect on the economies.

Question: In the United States, one of the big projects of Roosevelt was the rural electrification program, which had an enormous impact, especially in developing some of the poorest and most backward areas. What is the situation in your country, and how might the PBMR be brought into play beyond South Africa per se?

South Africa is in a fortunate position. It has probably mounted one of the largest electrification programs in history. In the last ten years, we have connected 3.8 million households. Electricity connectivity now rises above 70% of the economy. We are now starting the second big round of doing that, reaching even farther into our rural areas. So it shows we can do it.

Now, we have the advantage of a big grid, that allows us to do that. What is wonderful about this PBMR technology, is that it would allow three things to happen for a developing country. You could start your mining activity, but now at the mine (with the PBMR as a heat and power source), you could put your processing activities directly at the mining point, so you get value addition. And you can at the same time supply surrounding electrification for agricultural activities and for residential and household uses. So I think the flexibility is tremendous.

We are now working on a massive project from the Inga hydroelectric project in the Congo, which will have very big transmission lines traversing southern Africa. Now to be able to complement that distribution network with the pebble-bed reactors along the way, would allow for a genuine electrification program for agricultural, industrial, mining, and residential use. So this is an exciting set of possibilities that will allow the African economies to develop.

African economies are short of energy. They are short of infrastructure. And both of these can, to an extent, be solved by the PBMR over time. So we are looking at the next ten years or more, but it is very exciting.

Question: I and my colleagues were involved in 1978 in writing a book, *The Industrialization of Africa,* which among other things included a proposal for an African railroad grid. Africa still does not have a modern transport grid. More recently, we have emphasized the importance of "infrastructure development corridors," in which transport, energy, communications, and water systems are "bundled" together as the most efficient means to develop a large territory. Are you looking in that direction for Africa?

Yes, it's very interesting. Through the new partnership for Africa's development, NEPAD (New Partnership for Africa's Development), which is now an African Union project, there are a range of projects. We took up that idea of the corridors; in fact, we financed it. If you look at the Maputo development corridor, we did just that. We built a new highway, we are upgrading the rail line, we upgraded the telecommunications; and the Mozambican government is bringing in new operators for their port.

So you've got a whole logistical and telecommunications passage going down through to Moputo. Obviously it's easier there because you can use the strength of the South African economy. But you can do this in many African countries. So we are looking at that. And another point I should make, of course, is that with telecommunications you also need energy. The telecommunications industry in Africa is growing very fast, led in the main by the big South African telecommunications companies, and this is mainly wireless and mobile telephone, but that needs energy to get coverage. So again, you see the complementarity between the energy and the other infrastructure.

And quite clearly also with the rail system. There are a number of projects put forward in NEPAD that we are looking at developing. I would say that the main obstacle we are having on those projects at the moment is raising finances. In South Africa we can use more sophisticated public-private partnerships; our big state companies, rail companies can enter the capital markets successfully. Elsewhere in Africa, we are probably still dependent on a higher element of grant assistance, and that is a restraining factor in Africa at the moment which we need to change.

Question: Neo-liberal dogma says that governments should stay out of the economy. But in South Africa, the government plays a crucial role in infrastructure and economic development. How do you see this issue?

Our view is that you must examine your economic position at any point in time. The state will always play a role, also in the United States. But what role it plays and how it does that successfully is always a question of the moment. There are no religious dogmas on these things either way.

We have a very specific set of roles that we see the state playing. For example, the state will retain ownership of the electricity company, Eskom, because that gives us a much clearer strategic shareholding. But we then designed the total electricity system in a way that brings in private capital, through independent power producers (IPPs) and other areas. So you get a genuine structural partnership between the private and the public sectors. And you can adjust the proportionality of that partnership as the economic circumstances change.

For us in South Africa now, we need a strong state involvement; but the instruments we use are not necessarily the old-style ones. Our state-owned enterprises, as we call them, Eskom, our transport companies, and so on, have to be capable of entering the capital market, raising private capital at rates that are equal to the sovereign rate. So that puts a lot of pressure on the management and the boards to manage their companies efficiently. But we do give them an economic mandate. They are not profit-maximizers. We say that you have to meet these targets with social delivery.

For South Africa, we have an exceptionally important program. Because of poverty, we have a situation where we provide a basic free allowance of water, sewage treatment, and electricity to the poorest of poor households. So you get the basic allowance which is free, in terms of electricity, that is enough to keep your lights and cooking going for the year, and it allows kids to study, with a reasonable standard of living. We can do that because we use the instruments not just to maximize profit, but to achieve certain economic objectives.

But the mix with the private sector is very strong. We work closely with the private sector; we bring them into the investment plan. So this should not be some matter of religion, it should be a matter of concrete economics.

INTERVIEW: DIETER MATZNER

A Safe, Foolproof Nuclear Reactor

Dieter Matzner is General Manager of the Power Plant Division of PBMR. He was interviewed by Jonathan Tennenbaum on Jan. 30 at the London conference on the PBMR.

Question: I think that building a fundamentally new type of reactor has not happened for 40 years.

Yes, it's probably 40 years.

Question: What do you think are the most interesting and challenging features that people should keep in mind about the PBMR?

I think the most important feature by far is that the PBMR reactor design utilizes ceramic fuel, and the whole core design is made of ceramics—that is graphite materials which can withstand very high temperatures. The basic advantage of this is that the fuel is meltdown-proof. A core melt is made impossible essentially by the choice of materials, and therefore there is no need even for discussion about a probability of a core melt. That is the unique advantage of this high-temperature gas-cooled reactor.

Of course, there are many other advantages which this reactor has, starting with the whole idea that it has an on-line fueling system. There is only one other reactor in the world like that, Canada's CANDU reactor, a heavy water reactor [which uses natural uranium fuel].

This on-line fueling system has some very unique advantages. First and foremost, you can design the reactor with a very low excess reactivity, which means that in case of an

Geraldine Bennett/PBMR

Dieter Matzner (left) and Regis Matzie.

accident, you are essentially safeguarded by the design from a reactivity event [runaway chain reaction].

On-line fueling of course enables you to have much longer operational cycles between maintenance outages—planned shutdowns. In our case, the aim is to achieve an outage cycle of 30 days every six years, instead of the conventional 18-24 months' fueling and refueling cycles of light water reactors. In theory, this should give you an availability capability of about 97.5 percent, if, of course, all the mechanical equipment performs satisfactorily. But in principle, it's possible to achieve this very high availability. That, for the nuclear power generation industry, is very important.

The other thing is that because outage cycles are not determined by the fueling cycles, you have much greater flexibility to schedule maintenance outages. So, when there are, say, outages of other power-generating equipment, you are in a much better position to plan when the reactor must come offline for maintenance.

The other very important advantage of this pebble-bed reactor is that the pebble itself, the fuel form, lends itself perfectly for heat transfer, because the heat transfer around the sphere is optimal. It has a high surface area and stress distributions in the fuel are optimal because of its symmetrical fuel arrangement. That in itself is very unique. You are not restricted in any sense in the design. The other interesting fact about this reactor is that it is very proliferation-resistant. It is very efficient in burning plutonium, and in fact you would never deploy this technology for the purpose of breeding weapons-grade material.

Question: Do you mean that any plutonium that is generated in the reactor is burned up right away?

Yes, it is burned up right away, and there is very little plutonium left. To get enough plutonium from this reactor for a bomb would require something like 100,000 fuel elements to be diverted, which is unthinkable in a process inspected by an international authority like the International Atomic Energy Agency. Therefore, we see this as a very strong feature of this technology.

Furthermore, the technology lends itself very well to handling multiple fuel cycles. In South Africa we utilize UO_2, uranium dioxide, but it is very thinkable that different fuel cycles could be introduced into the same reactor without changing its design. First and foremost, in Germany the thorium-uranium fuel cycle was demonstrated very successfully. If you wish to do so, you could burn plutonium in this reactor, and even mixed oxide (MOX) fuels would be possible. All these different fuel cycles could be introduced into this reactor without actually needing to make any reactor design changes.

Question: Are there any other unusual features of the PBMR?

Another unique feature of this reactor technology is that it is unrivaled in terms of its high-temperature process heat application. In other words, this is the only carbon-dioxide-free high-temperature heat source available to mankind at this point in time. There is just no other way around this.

This reactor also has a very high burn-up rate of the fuel. The achievable burn-up at the present enrichment of 9.6 percent, is about 92,000 megawatt-days a ton of heavy metal. This leads to a significant reduction in high-level waste, and of course promotes the economics of the reactor from a fuel-efficiency point of view.

We have opted to couple this reactor technology with a gas-turbine cycle, which is unique, and that enables us to utilize the high-temperature capability of the reactor with a subsequent increase in efficiency. Normal reactor technologies coupled to the steam cycles give you on the order of 25-36 percent thermal cycle efficiencies, but we are on the order of 42 percent, which is a significant increase.

So in principle therefore, the specific safety features of a meltdown-proof core, the on-line fueling capability, the high efficiency capability, the process-heat applicability, the proliferation-resistance of this reactor technology, make it a very unique system design, and therefore it can be truly labelled as a so-called Generation IV reactor.

Question: How does the design complexity of the PBMR compare to that of the traditional light water reactor? Conventional light water reactors have extremely complex safety systems.

We have done a comparison to an AP1000 [Westinghouse] reactor, which is regarded as the Generation III-plus reactor and which relies much more on passive safety features than the traditional Generation II reactors. The PBMR essentially has about half the systems which the AP1000 reactor has, in order to support the whole power-generation process. I haven't got the exact figures to tell you now, but this study has been done and it is amazing how few systems the PBMR really utilizes.

Of course it is true that because of the very low energy-densities in the reactor, there are very large reactor structures, for a relatively small power output. That in itself means that there are few components, but these components are very large, and are essentially of the same size as a large light-water reactor.

Question: So, you save on the safety systems, but pay more for the components. And do you have confidence that in the overall cost, the PBMR will be competitive with the conventional light water reactor or even with coal generation?

You have to compare like with like. We cannot compete with a large coal-fired station located directly at the coal field. We have very cheap coal. So we must compare ourselves with power-generation options on the coastline, which is far away from our coal fields. There we can say that we are definitely competitive with combined-cycle baseload gas. There is no question about it—in fact, we are cheaper than that.

But I would expect that our technology is more expensive than the large light-water reactors. That is because the new generation of light water reactors, going up to 1,600 megawatts, are very large machines, and they have achieved economy-of-scale benefits by their larger size.

We have a definite disadvantage because of the small size, but it is for that reason that we picture ourselves not in the areas where large-scale power requirements are, but rather in the areas where you have 600 megawatts and less for power requirements. There are many countries, specifically in the developing world and most notably in Africa, which need only 200 or 400 or 600 megawatts of power for the country's grid. They would never be able to afford to buy a large 1,600-MW light water reactor.

Even South Africa, with its distribution grid, it would not be considered viable to have one large machine put onto the coast line, for the simple reason that if that machine goes offline for maintenance, or whatever, then you have no power.

So you still have to install the spinning reserves in the transmission grid in order to be able to compensate for the loss of such a machine. And benefits of size, in terms of power-generation, also bring financing risks. Because the financing risks of such a large power station are substantial, the utilization risk that it would not be utilized from day one, and the disruption factor of not being able to feed an area where a large machine goes off-line—these extract a premium in the price.

Question: How big a market do you envision developing countries to be for the PBMR, and where would the staffing come from?

The most important challenge with respect to the deployment of this technology in Third World countries, at the moment, is that most of these countries do not have the nuclear regulatory frameworks and regimes. And, therefore, we would have to find a way to be able to deploy these systems in these countries. I believe it is quite likely that in Africa, specifically sub-Saharan Africa, one could probably find a way where the South African licensing regimes, also with Eskom which is a major regional utility, would provide the operational support, within the regulatory framework from South Africa, under which these reactors could be licensed in these countries.

We see it as one of the operational benefits that the costs of power generation are less from a staffing point of view. We expect to have less staff on a station like this, because it is a simple station. Also because it is such a forgiving technology. In other words, this is probably one of the big advantages: If anything goes wrong, you have days, not minutes, before something happens. Even in the worst case, with this technology you will not have a catastrophic accident. You might lose your investment, but you will certainly not have a core melt. This is, of course, totally different from the other reactor technologies.

So from that perspective, I don't want to say that you can get away with unskilled and untrained personnel, but the severity of an accident, is much less, even if the plant doesn't have the most highly trained persons there. So this is exactly the technology of the future that can be deployed in the developing countries, where there is a shortage of skills and where the large power requirements are just not there.

Question: In terms of the plant construction, what are the requirements for the nuclear-quality components?

About 40 percent of the cost of the plant is in good-quality industrial equipment, like that you would find in any country, on the electrical side and chemical auxiliaries, civil structures, and so on. Of course, the reactor itself and the turbo machinery are high-quality components, and those always have to be imported or manufactured in factories which can make them according very stringent quality control. That's already a requirement in order to have not only safe operation but reliable operation. And that is the intent of any utility.

INTERVIEW: DR. REGIS MATZIE

How the U.S. Plans to Use the PBMR

Dr. Regis Matzie is Senior Vice President and Chief Technical Officer, Westinghouse Electric Company. He was interviewed by Jonathan Tennenbaum on Jan. 30 at the London conference on the PBMR.


Geraldine Bennett/PBMR

Question: How do you see the situation with PBMR applications in the U.S.A.?

We have started the early phases of licensing in the Nuclear Regulatory Commission (NRC) of the pebble-bed reactor, the so-called pre-application review. Pre-application means before the official design certification application, which is our process in the United States.

We're going to take about two years to complete pre-application review, and what we do in those two years is, first of all, educate the regulator about the design and the safety case. Second, we address a handful—six, seven, eight issues—that you need to get agreement on how to resolve them, before you submit a licensing report, a safety analysis report. We are picking issues that are very fundamental: What are the classifications of the systems and components, the safety classification? What are the codes and standards that you would use? What is the requirement for fuel qualification, and so on? So there's about six or seven of those that we are addressing, and we're resolving those while we're licensing this plant in South Africa.

So the current intention is, that once the South Africans are finished licensing the plant, so that they can start construction there, then we'll be ready to submit a similar application in the United States.

Question: Would you be building essentially the same design in the United States as the South African PBMR?

That is the current intention. The question is, I don't think we will be building what you would call a single unit, one module. Probably they'll come in four-packs, which is about 660-700 megawatts-electric. Another question, however, at this time, is, do we go ahead, and make the application for the electric plant, which would be a multi-module (probably four), or do we go ahead and license the process heat plant?

Now the process-heat plant is behind the electric plant in terms of the engineering, but we're working on that right now.

The other aspect is, that we haven't quite figured out how to approach the subject with the U.S. Nuclear Regulatory Commission. Can we license the basic safety case for one module, and then have just certain types of interface requirements, so that we can have a two-pack, four-pack, and eight-pack [of modules]?

You don't want to have to license each individual configuration on a modular reactor. You want to get a basic safety case. They have never done that before, so we are going to work through that issue with them.

Question: There has been discussion in the United States—including, for example, from Bill Ford, the head of the Ford Motor Company—of launching major government-supported programs to bring in hydrogen and other synthetic fuels, and new types of automobiles using hydrogen-based fuels. How are you thinking about these issues?

When I say the process-heat plant, there are specific types of applications. One of them is to generate syngas, another is to convert coal to liquid. Now South Africa SASOL is a major company that produces about one-third of all the petroleum products in South Africa; gasoline, diesel are converted from coal; these are all coal-based. SASOL does a coal-based conversion to liquid, that puts it into the transportation sector.

Question: And they also burn some of the coal to get energy for those processes?

Exactly right. There are a lot of emissions, as they are burning fossil fuels to do that conversion. What we want to do is develop the processes with the process-heat plant as a heat source, and also to generate hydrogen. Then hydrogen goes into the conversion process, and you can convert all the carbon to liquid petroleum. Right now, a significant percentage of the carbon goes up the stack when you're doing the current conversion process.

Question: What do you mean by liquid petroleum?

Diesel, gasoline, the whole set. And so we are looking at that with people like SASOL, British Petroleum, and so on. We have had preliminary discussions with many of them, and the question is, can we bring them along? It is a big step for people in the fossil industry to get involved in nuclear; it's kind of a psychological hurdle. So you have to bring them along. And of course today we do not have a product, where you can sort of show them the entire product.

We're designing the electric plant, and we're going to build that. So we'll prove the nuclear technology. We need to finish the design work on the process-heat plant plus the process side: How do you integrate the heat into, say, a coal-to-liquid or a syngas process, with the reformers and all the things that are on that side. Because there are different designs of those components, too.

We are going down that road. For the early stages, we're working with a process-heat company that does this for these types of companies, and we're getting there slowly.

Question: Will this also include hydrogen production?

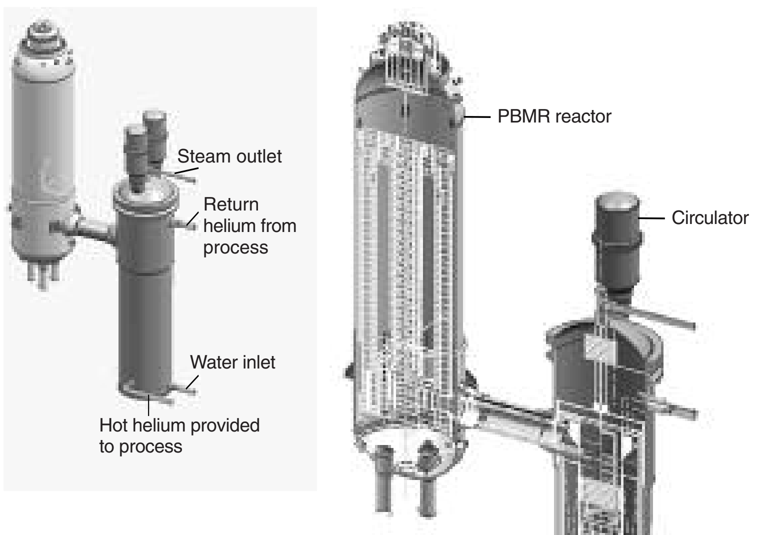
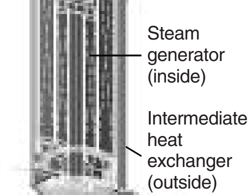
Thermochemical water-splitting is what we think is the most economical way to generate the hydrogen.

Question: I think that the inherent safety of the PBMR will be helpful in incorporating the industrial companies into the project.

It should be helpful in convincing them that this is not a technology they have to worry about. It should be helpful in allowing siting of the nuclear plant close to these chemical plants; what is the stand-off distance you need from the reactor—all this has to play together.

Question: What about the cost of the process-heat plants?

Right now, if you look at electricity, it's probably competitive with natural gas at around \$6 per million BTU. Hydrogen production is in the same range, because most hydrogen today is done by steam methane reforming, where they're now using natural gas. So electricity and hydrogen are in the same general range, and of course natural gas prices are above that today, and they will probably stay above that.

TYPICAL PBMR PROCESS HEAT SOURCE

The PBMR can be coupled to an industrial plant to produce high temperature process heat, process steam, and electricity, depending on the application required. Shown here is a PBMR reactor coupled in a series configuration with an intermediate heat exchanger, steam generator, and circulator. The hot helium from the PBMR reactor transfers its energy to the intermediate heat exchanger. There it passes through the steam generator before the circulator returns the helium to the reactor inlet.