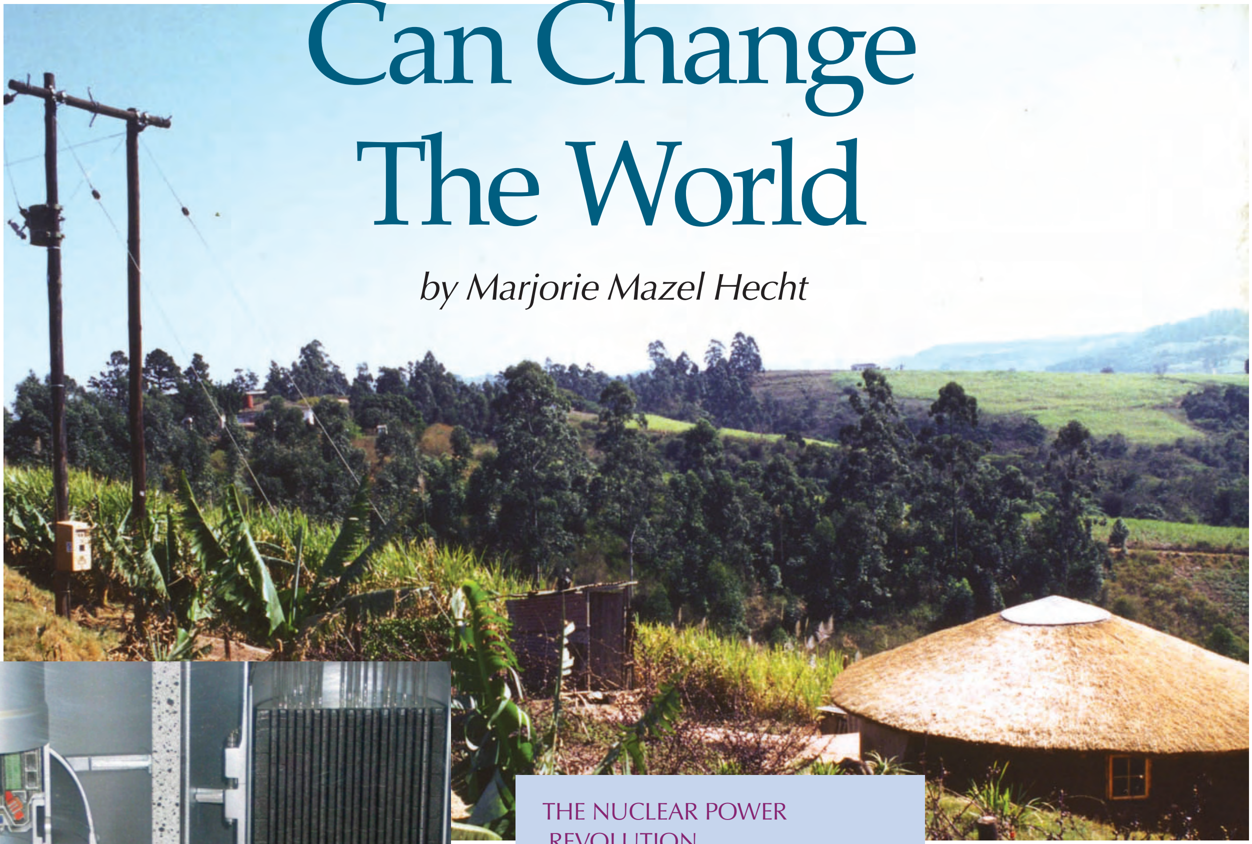
THE
NUCLEAR POWER
REVOLUTION

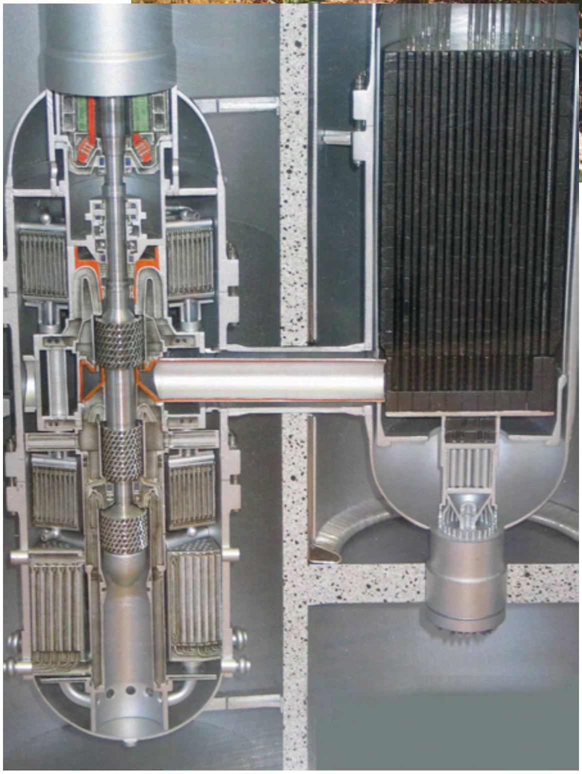
Modular High-Temperature Reactors Can Change The World

by Marjorie Mazel Hecht



Eskom

▲ *Electricity transmission line in South Africa.*



General Atomics

Far left: Tabletop model of the Gas-Turbine Modular Helium Reactor (GT-MHR) constructed by the Russian team working with General Atomics on the reactor design. When you push a button, simulated helium flows around the reactor core and power conversion vessel.

Sixty years into the atomic age, we are at the threshold of another revolution: the development of fourth-generation modular high-temperature reactors that are meltdown-proof, affordable, mass-producible, quick to construct, and very suitable for use in industrializing the developing sector. The key to these new reactors, as described here, is in their unique fuel: Each tiny fuel particle has its own "containment building."

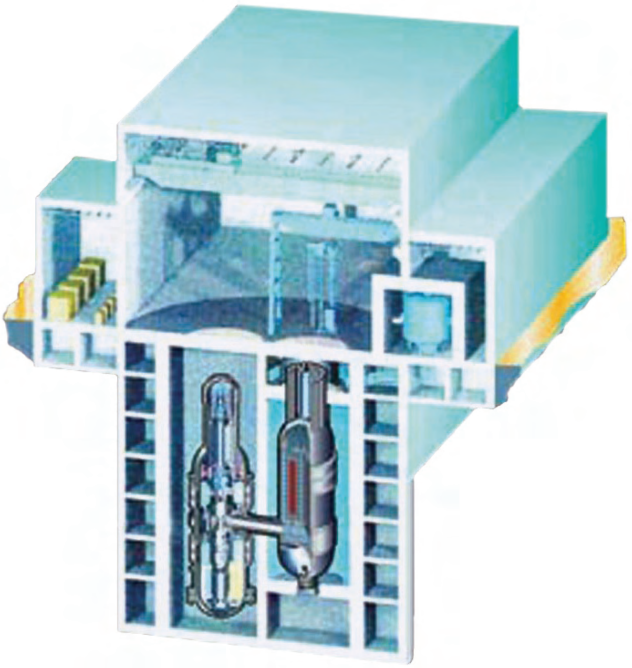
In the days of "Atoms for Peace," the 1950s and early 1960s, it was assumed that the development of nuclear power would rapidly bring all the world's people into the 20th Century, raising living standards, creating prosperity, allowing every individual to make full use of his creative ability. But this dream was not shared by the Malthusian forces, who, even after the massive slaughter of World War II, were determined to cull population further. These oligarchs, like the Olympian Zeus, who punished Prometheus for bringing fire to man, intended to rein in the atom, the 20th Century "fire." And so they did, creating a counterculture, a fear of science and technology, and an environmentalist movement to be Zeus' army to keep Prometheus bound.[1]

Today, we are at a point when nations, especially impoverished nations, can choose to fulfill the promise of Atoms for Peace, by going nuclear, starting with a modular high temperature reactor small enough, ~200 megawatts, to power a small electric grid and, at the same time, provide process heat for industrial use or desalinating seawater. As the economy grows, more modules can be added.

These fourth-generation reactors are fast to construct and affordable (because of their modularity and mass production), thus slicing through the mountain of statistical gibberish promoted by those Malthusians who disguise themselves as energy economists, like Amory Lovins. Now that several leading environmentalists have embraced nuclear as a clean energy solution, the hard-core Malthusians, including prominently Lovins and Lester Brown, have switched their main anti-nuclear argument to claim that nuclear is "too expensive." But because their mathematical calculations do not include the value of human life, Lovins et al. do not consider the human consequences of *not* going nuclear.

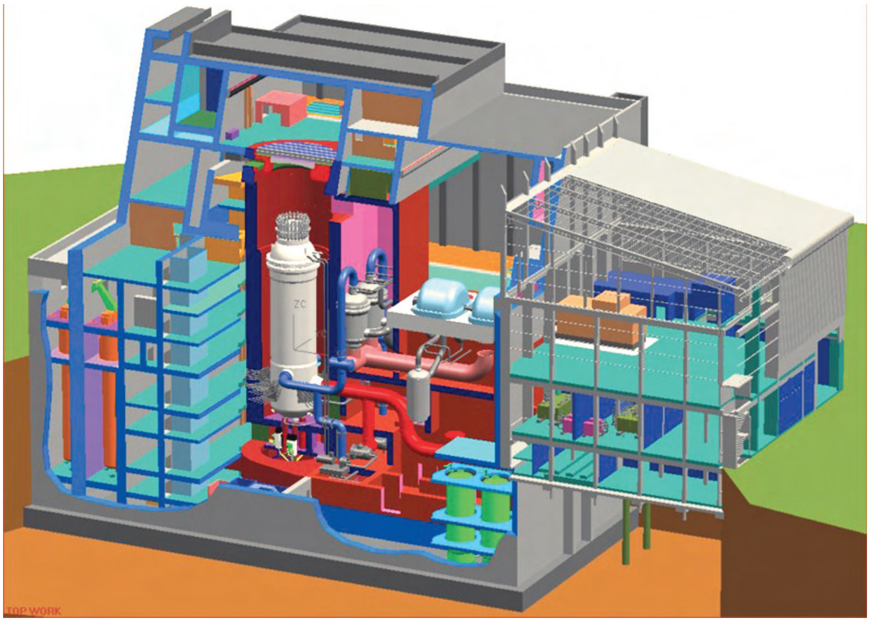
Energy Flux Density

If we are to support 6.7 billion people at a living standard worthy of the 21st Century, the world must go nuclear now, and in the future, develop fusion power. Fission is millions of times more energy-flux



General Atomics

Cutaway view of the prismatic modular reactor showing the reactor vessel (right) and the power conversion vessel (left), both located below ground. This GT-MHR design is for a 285-megawatt-electric reactor.



PBMR

A model of the pebble bed modular reactor, showing the reactor vessel at left, with the intercooler and recuperator units to the right. This design is for a 165-megawatt-electric reactor.

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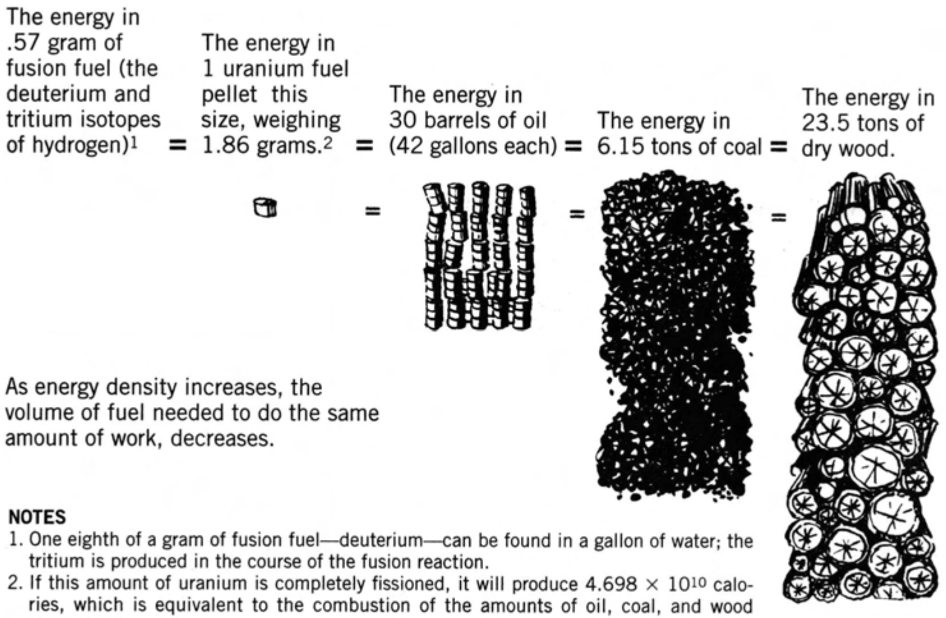
[1] See for example, Rob Ainsworth, "The New Environmental Eugenics: Al Gore's Green Genocide," *EIR*, March 30, 2007, www.larouchepub.com/eiw/public/2007/2007_10-19/2007 -13/pdf/36-46_713_ainsworth.pdf; also, Marsha Freeman, "Who Killed U.S. Nuclear Power," *21st Century*, Spring 2001, www.21stcenturysciencetech.com/articles/spring01/nuclear_power.html

Figure 1
FUEL AND ENERGY COMPARISONS

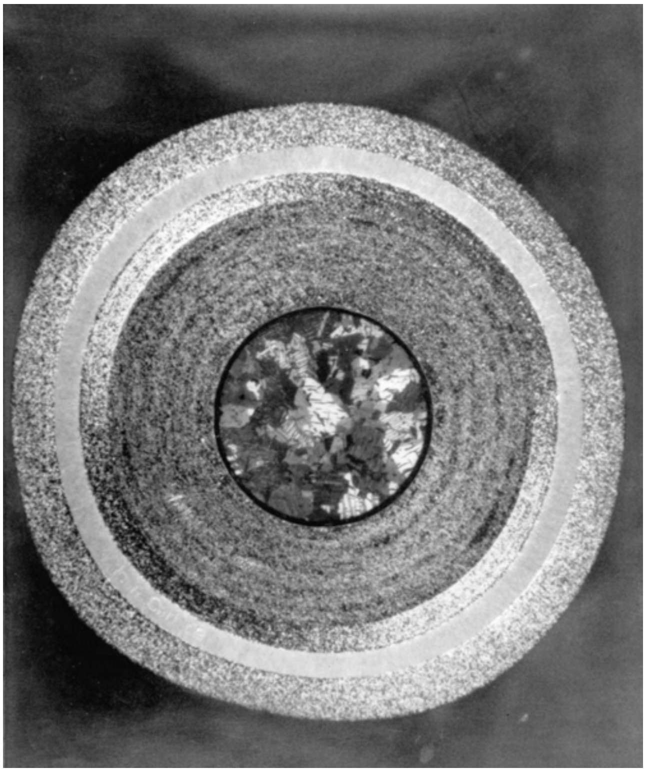
A tiny amount of fission fuel provides millions of times more energy, in quantity and quality, than other sources. With a closed nuclear fuel cycle (which reprocesses used nuclear fuel), and development of the breeder reactor, nuclear is not only a truly renewable resource, but is able to create more new fuel than that used to fuel the reactor.



NOTES

1. One eighth of a gram of fusion fuel—deuterium—can be found in a gallon of water; the tritium is produced in the course of the fusion reaction.
2. If this amount of uranium is completely fissioned, it will produce 4.698 × 10^{10} calories, which is equivalent to the combustion of the amounts of oil, coal, and wood shown here.

Source: Calculations made by Dr. Robert J. Moon



General Atomics

Inside a fuel particle: This is a magnified photograph of a .03-inch fuel particle, cut away to show the layers of ceramic materials and graphite surrounding a kernel of uranium oxycarbide fuel. The fission fuel stays intact in its "containment building" up to 2,000°C (3,632°F).

dense than any solar technology, and you can't run a modern industrial economy without this level of energy flux density.

Energy flux density refers to the amount of flow of the energy source, at a cross-section of the surface of the power-producing source. No matter what improvements are made in solar technologies, the basic limitation is that solar power is diffuse, and hence inherently inefficient. At the Earth's surface, the density of solar energy is only .0002 of a megawatt.[2]

Chemical combustion, burning coal or oil, for example, produces energy measured in a few electron volts per chemical reaction. The chemical reaction occurs in the outer shell of the atoms involved, the *electrons*. In fission, the *atomic nucleus* of a heavy element splits apart, releasing millions of electron volts, about 200 million electron volts per reaction, versus the few electron volts from a chemical reaction.

Another way to look at it is to compare the development of power sources over time, and the increasing capability of a society to do physical work: human muscle power, animal muscle power, wood burning, coal burning, oil and gas burning, and today, nuclear. The progress of a civilization has depended on increased energy flux density of power sources. The hand collection of firewood for cooking; tilling, sowing, and reaping by hand; treadle-pumping for irrigation (a favorite of the carbon-offset shysters): These are the so-called "appropriate" technologies that Malthusians advocate for the developing sector, precisely because they preclude an increase in population. In fact,

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[2] For a discussion of wind as energy, see "Windmills for Suckers: T. Boone Pickens' Genocidal Plan," by Gregory Murphy, *EIR*, Aug. 22, 2008. www.21stcenturysciencetech.com/Articles%202008/Windmills.pdf

these technologies cannot support the existing populations in the Third World—which is exactly why they are glorified by the anti-population lobby.

Although this report will discuss fourth-generation HTRs, to bring every person on Earth into the 21st Century with a good living standard, the nuclear revolution includes the development of all kinds of nuclear plants: large industrial-size plants, fast reactors, breeder reactors, thorium reactors, fission-fusion hybrids, and all sorts of small and even very small reactors. We will also need to fund a serious program to develop fusion reactors. But right now, the modular HTRs are ideal as the workhorses to gear up the global infrastructure building we need.

The Revolutionary Fuel

There are two types of high temperature modular gas-cooled reactors under development, which are distinguished by the way in which the nuclear fuel is configured: the *pebble bed* and the *prismatic* reactor. In the pebble bed, the fuel particles are fashioned into pebbles,

Figure 2
THE UNIQUE HTR FUEL IN A PRISMATIC CONFIGURATION (GT-MHR)

Each tiny fuel particle, three-hundredths of an inch in diameter, has a kernel of fission fuel at the center, surrounded by its "containment" layers. The fuel particles are mixed with graphite and formed into cylindrical fuel rods, about two inches long. The fuel rods are then inserted into holes drilled into the hexagonal graphite fuel element blocks, which measure 14 inches wide by 31 inches high. The fuel blocks, which also have helium coolant channels, are then stacked in the reactor core.

Source: General Atomics

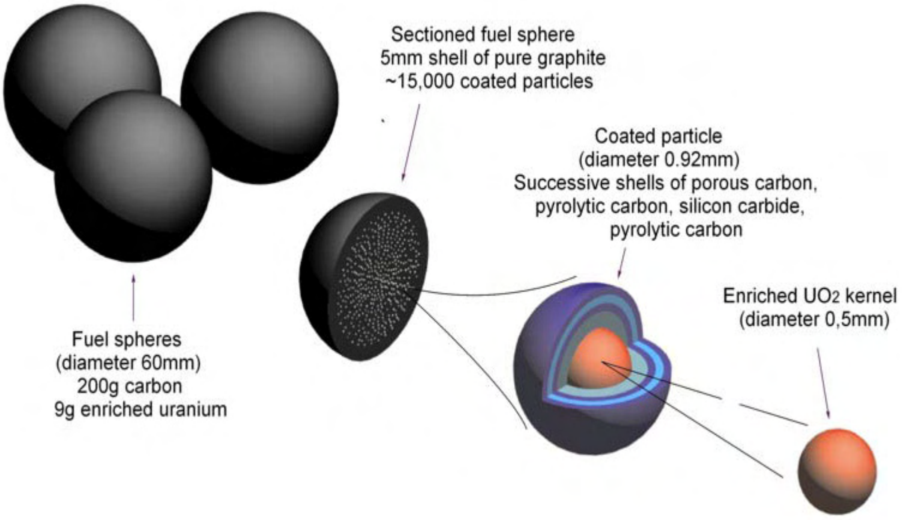

MULTIPLE LAYERS OF TOUGH, HIGH TEMPERATURE TOLERANT PYROLYTIC CARBON AND SILICON CARBIDE CONFINE THE RADIOACTIVE FISSION PRODUCTS AT THEIR SOURCE, IN THE CENTER OF THE FUEL PARTICLE.

COATED FUEL PARTICLES (TOP) ARE FORMED INTO FUEL RODS (RIGHT) AND INSERTED INTO GRAPHITE FUEL ELEMENTS (LEFT).

Figure 3
HTR FUEL FORMED INTO PEBBLES (PBMR)

The PBMR fuel particles are similar to those in Figure 2, with a kernel of fission fuel (uranium oxide) at the center (at right). Instead of being fashioned into rods, the particles are coated with containment layers and then inserted into a graphite sphere to form "pebbles" the size of tennis balls (at left). Each pebble contains about 15,000 fuel particles. Pebbles travel around the reactor core about 10 times in their lifetime. During normal operation, the reactor will be loaded with 450,000 fuel pebbles.

Source: PBMR



fuel balls the size of tennis balls, which circulate in the reactor core. In the prismatic reactor, the fuel particles are fashioned into cylindrical fuel rods, that are stacked into a hexagonal fuel block.

South Africa is developing the Pebble Bed Modular Reactor, the PBMR, and China has an operating 10-megawatt HTR of the pebble bed design, with plans to construct a commercial 200-megawatt unit starting in 2009.

General Atomics, based in San Diego, is developing the Gas Turbine Modular Helium Reactor, GT-MHR, which has a prismatic fuel rod design, and Japan is operating a 30-megawatt high temperature test reactor, HTTR, of the prismatic design.

Although the fuel configurations differ, both reactor types start with the same kind of fuel particles, and it is these tiny fuel particles that will revolutionize electricity generation and industry throughout the world. Developed and improved over the past 50 years, these ceramic-coated nuclear fuel particles, three-hundredths of an inch in diameter (0.75 millimeters), make possible a high-temperature reactor that cannot melt down.

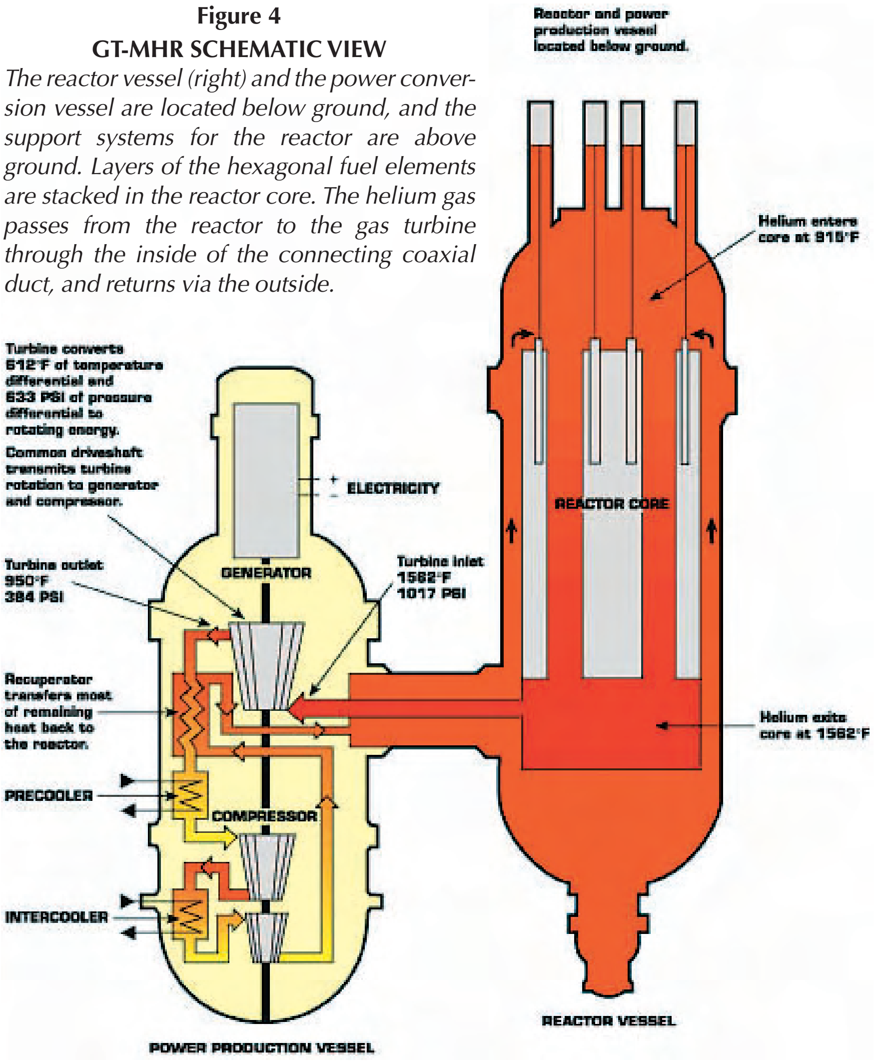


Figure 4
GT-MHR SCHEMATIC VIEW
The reactor vessel (right) and the power conversion vessel are located below ground, and the support systems for the reactor are above ground. Layers of the hexagonal fuel elements are stacked in the reactor core. The helium gas passes from the reactor to the gas turbine through the inside of the connecting coaxial duct, and returns via the outside.

At the center of each fuel particle is a kernel of fissile fuel, such as uranium oxycarbide. This is coated with a graphite buffer, and then surrounded by three or more successive containment layers, two layers of pyrolytic carbon and one layer of silicon carbide. The nuclear reaction at the center is contained inside the particle, along with any products of the fission reaction. The ceramic layers that encapsulate the fuel will stay intact up to 2,000°C (3,632°F), which is well above the highest possible temperature of the reactor core, 1,600°C (2,912°F), even if there is a failure of the coolant.

The Chinese tested this in the HTR-10 in September 2004, turning off the helium coolant. The reactor shut down automatically, the fuel temperature remained under 1,600°C, and there was no failure of the fuel containment. This demonstrates both the inherent safety of the reactor design, and the integrity of the fuel particles, stated Frank Wu, CEO of Chinery, the consortium appointed by the Chinese government to head the development project.

As for the waste question: The HTRs produce just a tiny amount of spent fuel, the less to store or bury. But the rational question is, why bury it and throw away a resource? Why not reprocess it into new nuclear fuel?

General Atomics had an active research program investigating the reprocessing of spent fuel from the HTR, but when the United States gave up reprocessing in the 1970s under the banner of "nonproliferation," the facility was converted to do other research. As one longtime General Atomics nuclear engineer told me, reprocessing used HTR fuel is absolutely possible—you just have to want to figure out how to do it.

Fission in the HTR

Conventional fission reactors work much like their predecessor technologies. The fission reaction produces heat, the heat boils water to create steam, and the steam turns a turbine, which is attached to a generator to produce electricity.

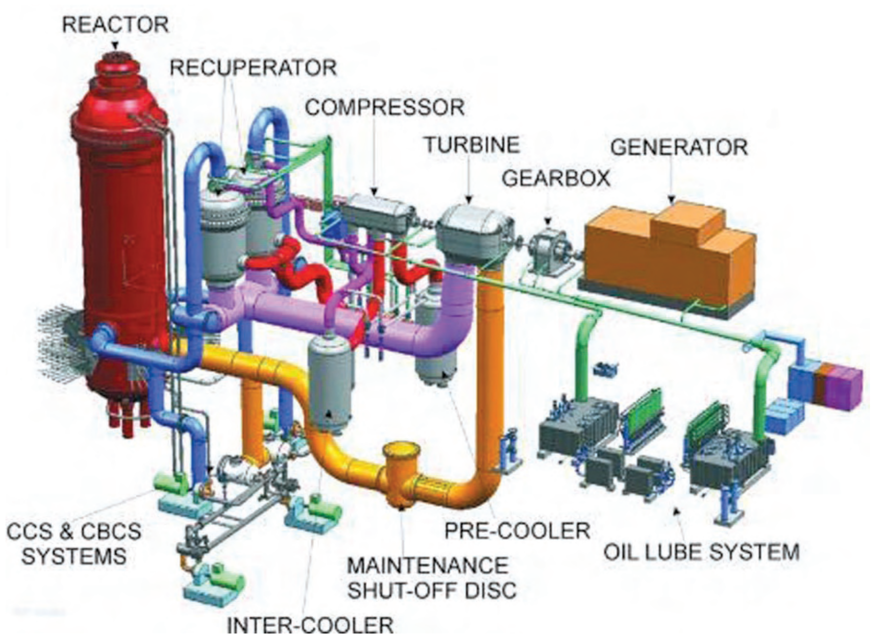


Figure 5
PBMR REACTOR CONFIGURATION

The reactor vessel (left) and the systems for power conversion in the PBMR. The PBMR fuel is in the form of tennis-ball size pebbles, which circulate in the reactor vessel. Helium gas conveys the reactor heat to the gas turbine and generator; the helium is then cooled, recompressed, and reheated before returning to the reactor vessel.

Source: PBMR

The fourth-generation reactors also use the fission reaction to produce heat, but instead of boiling water, the heat is used to heat helium, an inert gas, which then *directly* turns a turbine, which is connected to a generator to produce electricity. By eliminating the steam cycle, these HTRs increase the reactor efficiency *by 50 percent,* thus reducing the cost of power production.

An obvious question is: How does the fission chain reaction occur if all the fission products are contained inside the fuel particles? The key is the neutron.

When the atomic nucleus of uranium splits apart, it produces heat in the form of fast-moving neutral particles (neutrons) and two or more lighter elements. To sustain a controlled fission chain reaction, every nucleus that fissions has to produce at least one neutron that will be captured by another uranium nucleus, causing it to split. The fission process is very fast; ejected neutrons stay free for about 1/10,000 of a second. Then they are either captured by fissionable uranium, or they escape without causing fissioning, to be captured by other elements or by nonfissionable uranium. Free neutrons can travel only about 3 feet.

All nuclear reactors are configured to create the optimum geometry for neutron capture by fissionable uranium. The point of a controlled fission reaction is to engineer the reactor design to capture the right proportion of slow neutrons in order to produce a steady fission reaction. (It is the slower neutrons that cause fissioning; the fast neutrons tend to be captured without causing fissioning.) For this purpose, reactors have *control rods,* made of materials like neutron-absorbing boron, that are raised or lowered to absorb neutrons, and *moderators,* made of a lighter element like carbon (graphite), that slow the neutrons down.[3]

In conventional nuclear reactors, water is the usual moderator, and the fission products stay inside the reactor core's fuel assembly. In the HTR, each tiny fuel particle contains the fission products produced by its uranium fuel kernel; only the neutrons leave the fuel particles.

Helium Gas: Heats and Cools

The beauty of the high temperature reactor, and the reason that it can attain such a high temperature (1,562° F, or 850°C compared with the 600°F of conventional nuclear plants) lies in the choice of helium, the inert gas that carries the heat produced by the reactor. Helium has three key advantages:

- Helium remains as a gas, and thus the hot helium can directly turn a gas turbine, enabling conversion to electricity without a steam cycle.
- Helium can be heated to a higher temperature than water, so that the outlet temperature of the HTR can be higher than in conventional water-cooled nuclear reactors.
- Helium is inert and does not react chemically with the fuel or the reactor components, so there is no corrosion problem.

The helium circulates through the nuclear core, conveying the heat from the reactor through a connecting duct to the turbine. Then it passes through a compressor system, where it is cooled to 915°F (490°C), and re-enters the nuclear core. The use of helium as both the coolant and the gas that turns the turbine simplifies the reactor by eliminating much of the equipment (and expense) of conventional reactors.

The high heat that is produced can be coupled with many industrial processes, such as desalination of seawater, hydrogen production, coal liquefaction, and so on. These reactors are also small enough to be located on site for some industries, producing both electricity and process heat. The LaRouche plan for the Eurasian Land-Bridge and the World Land-Bridge,

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[3] For more detail, see "Inside the Fourth-Generation Reactors," *21st Century,* Spring 2001.

for example, envisions these HTR reactors as the hub of new industrial cities across Eurasia and the harsh Arctic environment of eastern Russia, linked by high-speed and magnetically levitated railways.

Direct Conversion to Electricity

The HTRs, as noted above, gain efficiency by eliminating the steam cycle of conventional nuclear reactors (the heating of water to turn it into steam, which then turns a turbine). Instead, the helium gas carries the heat of the nuclear reaction to *directly* turn a gas turbine.

Like conventional nuclear reactors, the first high temperature reactors—Peach Bottom in Pennsylvania and Fort St. Vrain in Colorado, for example—used a steam cycle. The Chinese HTR-10 also uses a steam cycle, but plans are to switch to a direct conversion system in its later models.

It only became possible to use the Brayton direct-cycle gas turbine with the HTRs after advances in industrial gas turbine use, and work carried out at the Massachusetts Institute of Technology during the 1980s specifically for coupling HTRs with a Brayton cycle. There were also advances in related systems, such as the recuperators and magnetic bearings. Taken together, these advances give the HTRs an overall efficiency of about 48 percent, which is 50 percent more than the efficiency of conventional nuclear reactors.

Multiple Safety Systems: Meltdown Proof

The modular HTRs are inherently safe, because they are designed to shut down on their own, without any human operator's intervention. Even in the unlikely event that all the cooling systems fail, the reactor would shut down safely, dissipating the heat from the core without any release of radioactivity.

The built-in safety systems, as discussed above, include the unique fuel particle containment: the fission products stay inside these "containment" walls.

Another safety feature is the reactor's

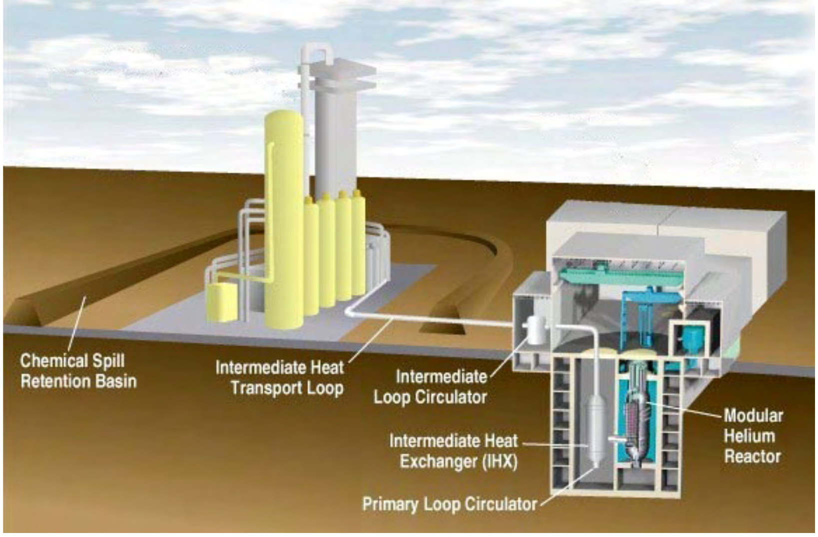

Figure 6

GT-MHR COUPLED WITH HYDROGEN PRODUCTION PLANT

This General Atomics design couples 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.

Source: General Atomics

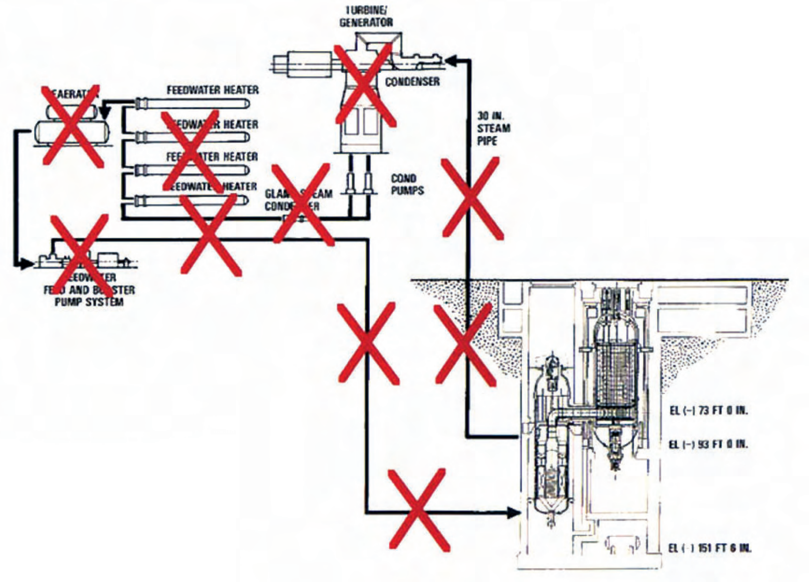

Figure 7

SIMPLICITY OF DIRECT-CONVERSION POWER GENERATION

Using direct conversion with a gas turbine eliminates the steam cycle from the HTR, as shown here. At the same time, direct conversion increases the efficiency of the reactor by 50 percent.

Source: General Atomics

"negative temperature coefficient" operating principle: If the operating temperature of the reactor goes up above normal, the neutron speed goes up, which means that more neutrons get captured without fissioning. In effect, this shuts down the chain reaction. Additionally, there are certain amounts of "poisons" present in the reactor core (the element erbium, for example), which will help the process of capturing neutrons without fissioning, if the operating temperature goes up.

The first line of safety in regulating the fission reactor is, of course, the control rods, which are used to slow down or speed up the fissioning process. But if the control rods were to fail, the reactor is designed automatically to drop spheres of boron into the core; boron absorbs neutrons without fissioning, and thus would stop the reaction.

Additionally, there are two external cooling systems, a primary coolant system and a shutdown coolant system. If both of these should fail, there are cooling panels on the inside of the reactor walls, which use natural convection to remove the core heat to the ground. Because the reactor is located below ground, the natural conduction of heat will ensure that the reactor core temperature stays below 1,600°C, well below the temperature at which the fuel particles will break apart.

The graphite moderator also helps dissipate heat in a shutdown.

In addition to the successful Chinese HTR-10 test shutdown, a similar test was carried out on the AVR, the German prototype for the pebble bed, at Jülich. In one test, reactor staff shut down the cooling systems while the reactor was operating. The AVR shut itself down in just a few minutes, with no damage to the nuclear fuel. In other words, no meltdown was possible.

The HTR: A Manhattan Project Idea

The idea of a high-temperature gas-cooled reactor dates back to the Manhattan Project and chemist Farrington Daniels, who designed a nuclear reactor, then called a "pile," which had "pebbles" of fission fuel whose heat was removed by a gas. Daniels patented his idea in 1945, calling it a "pebble bed reactor," and the Oak Ridge National Laboratory began to work on the concept. But Daniels's idea was dropped, in favor of the pressurized water reactor, and the group working with Daniels went on to design the first nuclear reactor for the *Nautilus* submarine.[4]

Later, Great Britain, Germany, and the United States developed high-temperature gas-cooled reactors. In Germany, Prof. Rudolf Schulten began working on a pebble-bed type reactor,

Prof. Rudolf Schulten (center), who developed the pebble bed design and built the first pebble bed reactor, was made a guest professor of Tsinghua University, where China's HTR-10 was built on the pebble bed model.

Petr Pavlicek/IAEA

EIRNS

Chinese technicians in the control room of the experimental HTR-10. China plans to construct a commercial-size 200-megawatt HTR starting in 2009.

Inset: Mary Burdman of EIR *holding a Chinese fuel pebble on a visit to the HTR-10 in 2001.*

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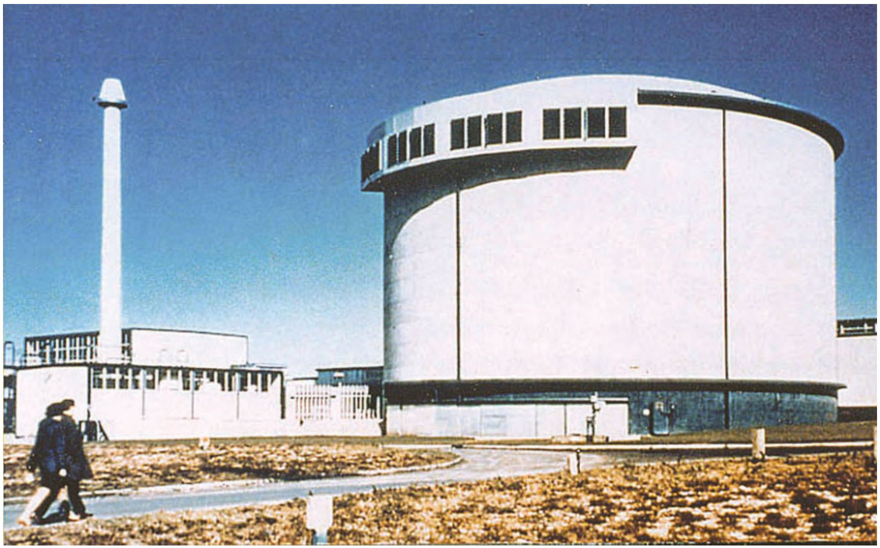
[4] Manhattan Project veteran Alvin M. Weinberg, who headed Oak Ridge National Laboratory, describes this in his autobiography, *The First Nuclear Era: The Life and Times of a Technological Fixer* (Woodbury, N.Y.: American Institute of Physics Press, 1994).

and designed the 40-megawatt AVR pebble-bed reactor at Jülich, which operated successfully from 1966 to 1988, producing power for the grid and yielding a wealth of research data. Both this and a subsequent larger HTR were shut down in 1988, as the anti-nuclear movement rode the wave of Chernobyl fear. South Africa's PBMR, as well as the Chinese HTR-10, makes use of the Schulten pebble-bed system, with innovations particular to each of the two new designs.

In Europe, 13 countries collaborated on the experimental high temperature gas reactor called Dragon, built in England in 1962. The 20-megawatt Dragon operated successfully from 1964 to 1975, testing materials and fuels, and its experimental results were used by later HTR projects, including the THTR and the Fort St. Vrain HTR.



Courtesy of General Atomics

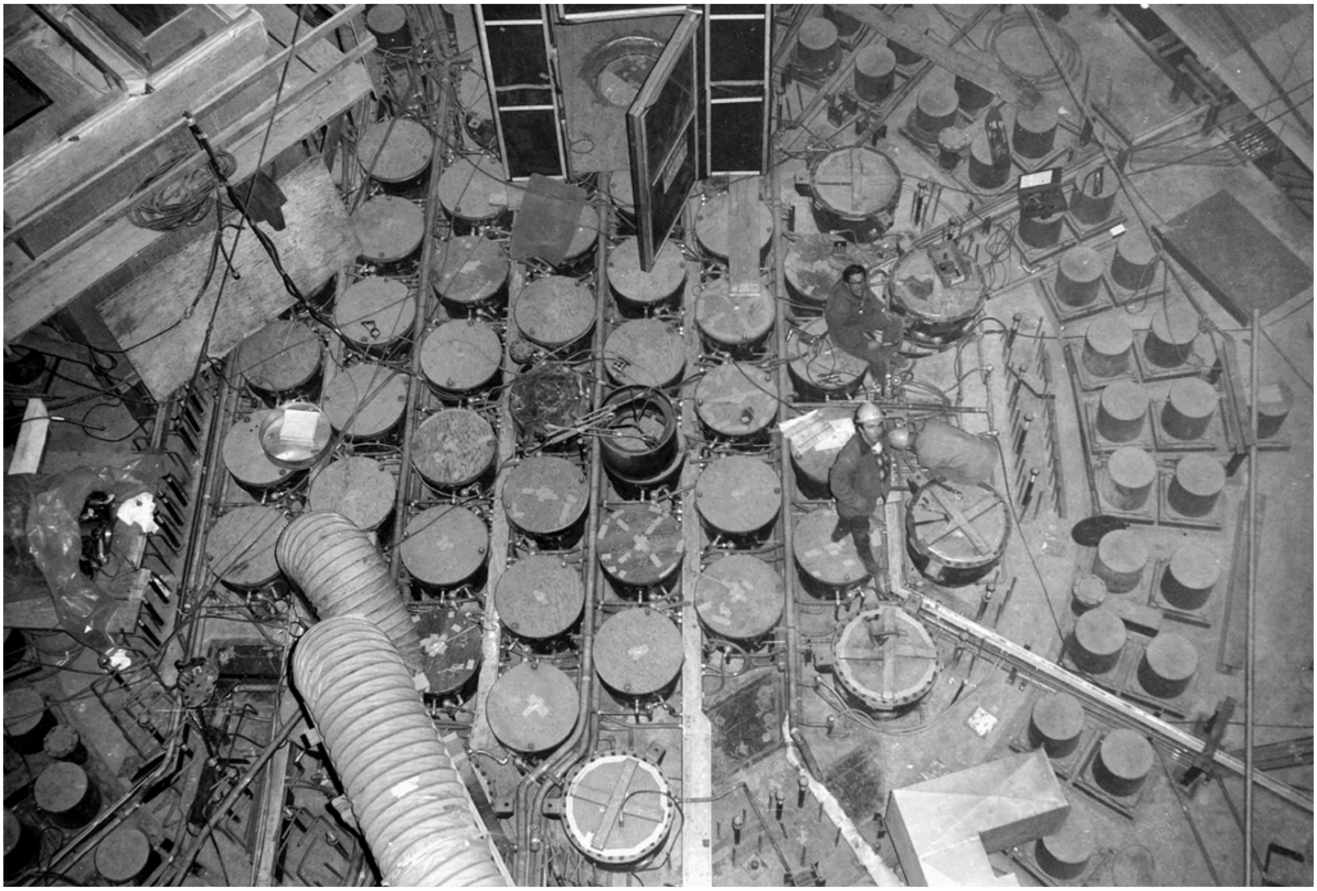
The 20-megawatt Dragon high-temperature nuclear reactor in England, operated from 1964 to 1975 as an experimental project of several European countries.

In the United States, Peach Bottom 1 in Pennsylvania was the first commercial HTR, put into planning in 1958, just a year after the first U.S. nuclear plant went on line at Shippingport, Pennsylvania. Built by General Atomics and operated by the Philadelphia Electric Company, the prototype HTR operated successfully from 1966 to 1974, producing power for the grid and operating information on HTRs. As General Atomics' Linden Blue characterized it, Peach Bottom worked "like a Swiss watch." Unit 1 at Peach Bottom was followed by two conventional boiling water reactors at the same site.

General Atomics next built a larger HTR, the 330-megawatt Fort St. Vrain plant in Colorado, which operated from 1977 until 1989, using a uranium-thorium fuel. Unfortunately mechanical problems with the bearings—a non-nuclear problem—made the plant too expensive to operate, and it was shut down. (Gen-

Courtesy of Exelon Nuclear

The Peach Bottom nuclear power plant in Pennsylvania, the first U.S. commercial high-temperature reactor, operated "like a Swiss watch." Unit 1 is the white-domed structure, at left. Two conventional boiling water nuclear reactors are operating now at the site.



General Atomics

Inside the reactor core of Fort St. Vrain high-temperature reactor in Colorado, during construction. The 330-megawatt plant had mechanical problems with the bearings, which made it uneconomical to operate, and it was shut down in 1989.

eral Atomics' Linden Blue discusses this in the accompanying interview.) Later, Fort St. Vrain was transformed into a natural gas power plant.

General Atomics continued its HTR research through the 1980s and in 1993, began a joint project with the Russians to develop the GT-MHR, with a focus on using the reactor to dispose of surplus Russian weapons-grade plutonium, by burning it as fuel. The HTR is particularly suitable for this purpose, because of the high burnup of fuel (65 percent). Later in the 1990s, the French company Framatome and Japan's Fuji Electric joined the program.

Today the conceptual design for the GT-MHR is complete and work continues to advance on the engineering, but construction cannot start until sufficient funds are available. The site selected for the reactor is Tomsk-7, a formerly "secret city" for production of plutonium and weapons, today known as Seversk.

In 2006, the University of Texas at the Permian Basin selected the GT-MHR design as the focus for a new nuclear research reactor, to be built in West Texas near Odessa.[5] General Atomics, Thorium Power, and the local communities contributed funds for the initial conceptual design. Now the University has just signed a Cooperative Research and Development Agreeman with Los Alamos National Laboratory, to develop a "pipeline of new nuclear reactor engineers" (a Bachelors degree program) to be ready immediately for working in power plants, national laboratories, or one of the U.S. nuclear agencies. According to the agreement, Los Alamos will send its scientists and engineers to the campus to teach and lead research, along with R&D equipment. The University's engineering staff will work with Los Alamos on research and joint seminars.

The project is named HT^{3}R (pronounced "heater"), which stands for high-temperature teaching and test reactor. Dr. James Wright, who manages HT^{3}R, told this writer that the initial efforts will be "geared toward developing any non-nuclear simulation or calculation that will move the HTGR technology forward to commercial deployment." Wright said that they would like to "eventually find a way to participate in an advanced reactor test facility like the HT^{3}R, but we are not necessarily tied to any particular design. Again, our goal is to move the HTGR technology to commercial deployment as fast as possible." In Wright's personal view, such a first reactor could be built without Federal involvement or money, "if the economics are right."

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[5] See an interview with James Wright, "Texas University to Build HTR Reactor," www.21stcenturysciencetech.com/2006_articles/spring%202006/Nuclear_Report.pdf

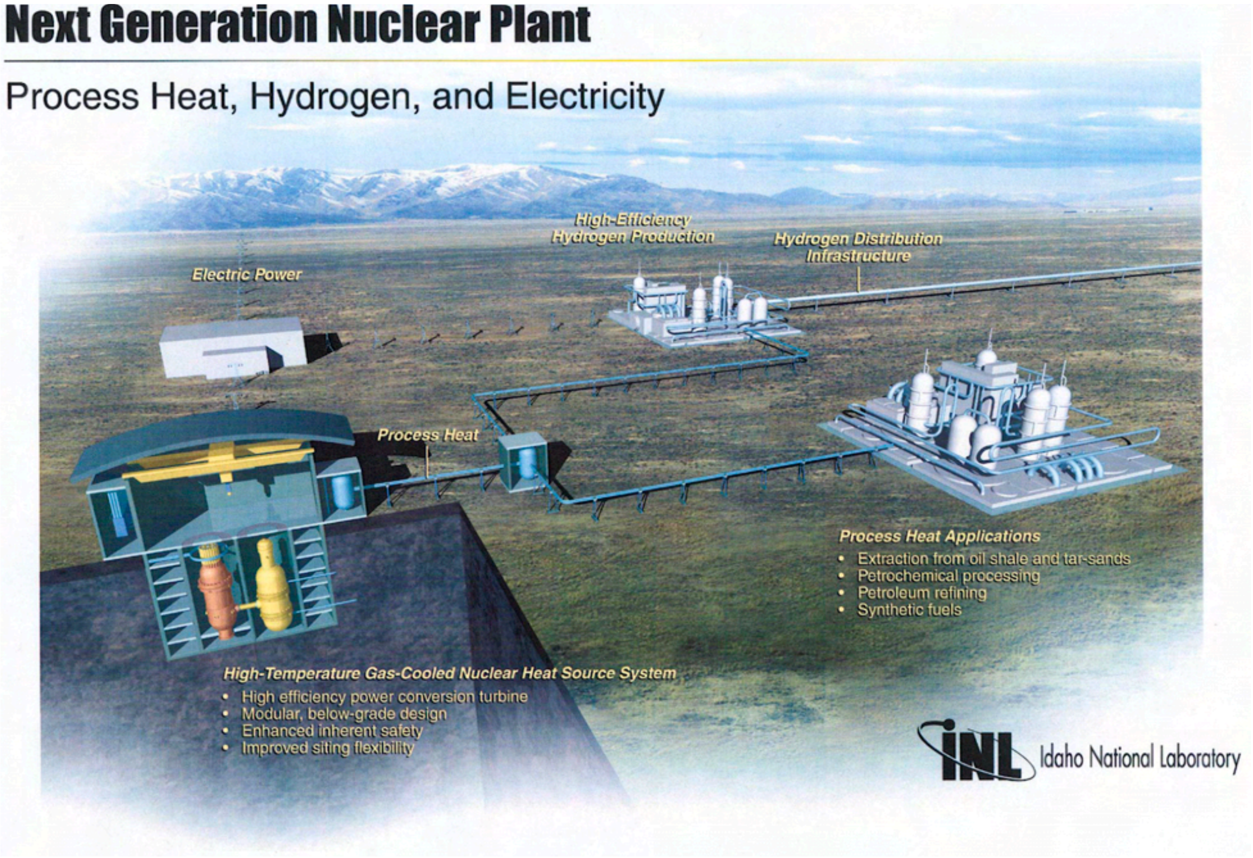

Figure 8

The Idaho National Laboratory's conception of the Next Generation Nuclear Plant, a high-temperature gas-cooled reactor which would be used to produce electricity and high-quality heat for the production of synthetic fuels like hydrogen, and for process heat applications in industry. The U.S. Next Generation Nuclear Plant program, based at the Idaho National Laboratory has not yet selected an HTR design (pebble bed or prismatic), and is on a very slow trajectory, aiming for a commercial plant in 2030. Meanwhile, China and Japan have working experimental HTRs, and South Africa plans to move to construction with the PBMR next year.

Will the U.S. Catch Up?

The Department of Energy's Next Generation Nuclear Plant program plans to put a commercial-size HTR on line . . . by the year 2030. So far, two industry groups have received a small amount of funding for design studies, and there is a target date of 2021 for a demonstration reactor of a type (pebble bed or prismatic) to be determined. But even that slow timetable is not sure, given the budget limits and lack of political priority.[6] This HTR project, called the Very High Temperature Reactor, is based at Idaho National Laboratory, and is planned for coupling with a hydrogen production plant. At the slow rate it is going, the United States, a former nuclear pioneer, may find itself importing this next-generation technology from a faster advancing nation.

The other problem is that the Next Gen program has taken a backseat to the Bush Administration's Nuclear Energy Partnership (GNEP) program. The political thrust of the Department of Energy's GNEP is to prevent other nations (especially those unfavored nations) from developing the full nuclear fuel cycle, by controlling the enrichment and supply of nuclear fuel. In line with nonproliferation, GNEP's focus is on building a fast (breeder) reactor that is "proliferation proof"—one that would burn up plutonium, preventing any diversion for bomb making. Nonproliferation, an obsession with both the Bush Administration and the Democrats, in reality is just a euphemism used for years by the Malthusian anti-nuclear movement to kill *civilian* nuclear power.[7]

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[6] This program is discussed in "It's Time for Next Generation Nuclear Plants" by Marsha Freeman, *21st Century,* Fall 2007, www.21stcenturysciencetech.com/Articles%202007/NextGen.pdf

[7] For more on this topic, see "The Neo-cons Not Carter Killed Nuclear Energy," *21st Century,* Spring-Summer 2006, www.21stcenturysciencetech.com/2006_articles/ spring%202006/Wohlstetter.pdf; and "Bush Nuclear Program: Technological Apartheid," *EIR,* July 6, 2007.

INET

Will the U.S. be left behind? PBMR and China both plan to start HTR construction in 2009. Above: Artist's depiction of planned site for a commercial HTR in China.

Below: Artist's illustration of the planned PBMR facility at Koeberg, South Africa, near the location of two conventional nuclear reactors.

PBMR

It would make sense under the Next Gen program for the United States to build a prototype GT-MHR, because the South Africans are building a PBMR, and this would give the world working models of each type. But at the present pace and budget, without a major commitment on the level of the Manhattan Project, a U.S. demonstation reactor is barely on the horizon.

The problem is not with the technology. Speaking at a press conference on the HTR in Washington, D.C. on Oct. 1, Dr. Regis Matzie, Senior Vice President & Chief Technology Officer at Westinhouse, who chaired the HTR 2008 conference, stated flatly, "We don't have a national priority" on building an HTR, and other countries which do—South Africa and China, for example—can move faster. At the same press conference, Linden Blue summed up the current HTR situation philosophically. With any new technology he said, you have an initial period of ridicule; then the technology is viciously attacked; and then, finally, the technology is adopted as self-evident. Soon after that, Blue said, everyone will be commenting on that first HTR, "What took you so long?"

The nuclear power revolution is now within our grasp, here in the United States, in South Africa, in China, in Japan, in Europe. The cost of developing the HTR is minuscule, in comparison with the trillions of dollars being sunk into the unproductive and losing gamblers on Wall Street. The cost of *not* developing these fourth-generation reactors will be measured in lives lost, and perhaps civilizations lost.

INTERVIEW: LINDEN BLUE

The Modular High-Temperature Reactor: Its Time Has Come!


Marjorie Hecht

Linden Blue is vice chairman of General Atomics in San Diego, where he is responsible for the development of the advanced gas-turbine modular helium reactor (GT-MHR). General Atomics, which has a wide range of high-technology projects, has been involved with the development of HTRs for more than 50 years. Mr. Blue was formerly CEO of Beech Aircraft and general manager of Lear Jet, both in Wichita, Kansas. He was interviewed by Marjorie Mazel Hecht on Oct. 27, 2008.

Question: Your outlook has always been visionary: You see the need worldwide for a reliable, safe power source. What do you think will enable us to turn the corner, and begin mass production?

Historically we've gotten our economics in nuclear by making the plants bigger and bigger, and getting "the economies of size scale." But the reality is that everything we have in life that is, let's say, economical, has gotten that way because it's *mass produced.* Everything from coffee cups to cars. There are no exceptions that I can think of right now.

Well, obviously, we're not going to produce nuclear reactors in the numbers that we've produced cars, but perhaps a better analogy would be airplanes, which are produced in serial production, in relatively low numbers. The learning curve get the costs down through serial production. I think it's possible that if you get the right sized gas reactor, you can have these produced in quantities where you get all the benefits of mass production, with favorable learning curves.

Said another way, there are two ways to get economy: One is to make the reactors bigger and bigger, which seems to have reached the point of diminishing return, and the other way is through mass-production.

The latest projection for light water reactors, because of the run-up of commodity prices, has been as high as $6,000 per kilowatt, and if you have a 1,200-megawatt reactor, you're looking at $7 or $8 billion. That's a huge amount, to say nothing of the sometimes disruptive effect of dropping 1,000 or 1,200 megawatts into a given market.

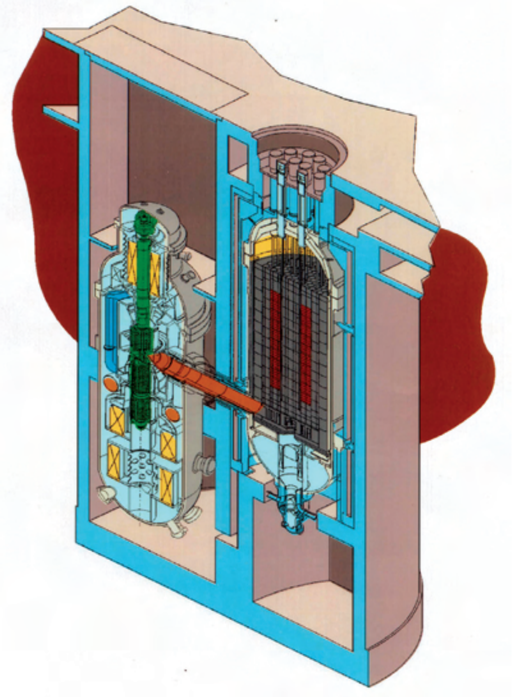
> *"Technology is a wonderful thing! People invent better things to solve problems. And this is exactly what's happened here. Over this 50-year period, the reactor design has improved dramatically. We've made mistakes, and we've cured them. And now we have something that is so safe, and so economical, and so efficient, and so non-polluting, that its time has come."*

Question: You're talking about the capital cost here.

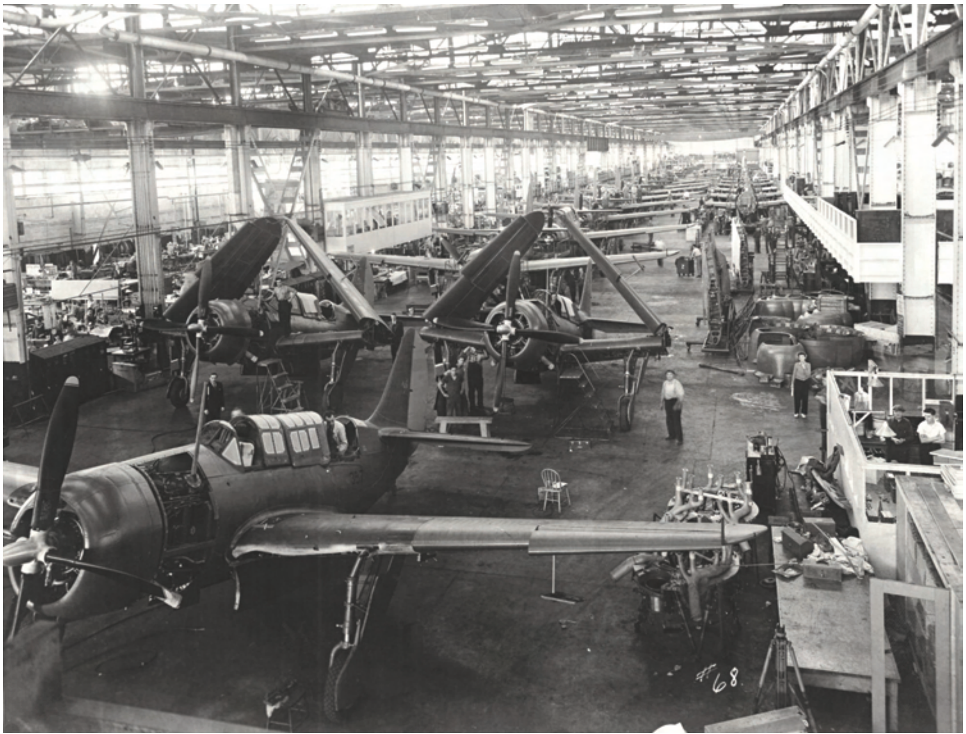
Yes, that's the capital costs, construction. The operating economics are affected by the 50 percent greater efficiency of the gas reactor. Overall, you have an equation that's pretty hard to beat.

Question: And the GT-MHR is designed at a size to be mass produced?

Yes, a good size would range from 100 to 300 megawatts for the HTR, versus 1,200 megawatts for a conventional water reac-


Cutaway view of the GT-MHR, showing the reactor vessel (right) and power conversion vessel. The helium gas directly drives a gas turbine generator, which gives the reactor nearly a 50 percent increase in efficiency.

General Atomics



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Serial production, as with these airplanes during World War II, will enable the fourth-generation nuclear reactors to be economical. Here, an airplane assembly line at the Canadian Car and Foundry Co., in Fort William.

tor. You're duplicating the learning in the production process six times as frequently, and that makes a huge difference. So, the modular approach has always been attractive. Now it's mostly a matter of doing it.

The history of how the light water reactors came about—they came out of submarines. They were the only ones that were available at the time. They've served us well, but the question is, is that what we want to build a lot of for the future? My answer would be no: You want to build the safest possible reactor that you can, and the most economical. I believe that takes you to the modular approach for economy and the inherent safety approach for safety. To do that, you need ceramic fuel and a Brayton cycle. Helium as the heat transfer fluid enables both.

When you are dealing with higher temperatures of a gas reactor and a Brayton cycle instead of a Rankine cycle, you get on the order of 50 percent more thermal efficiency. That is *huge* in something as basic as primary energy. You create heat and turn it into some kind of work. Steam cycles have been doing that very well, ever since Robert Fulton and the steamboat, but there's a better way, if you can use a fluid like helium to directly drive a turbine. So, to go from 33 percent efficiency to 48 percent—nearly a 50 percent increase in efficiency—that's tremendously significant. That lays the foundation for considerably greater economics.

Question: How are we going to gear up to get this done? What manufacturing resources exist already, and what would we need to create?

I think we really have all the resources to do it. Let's just walk through that.

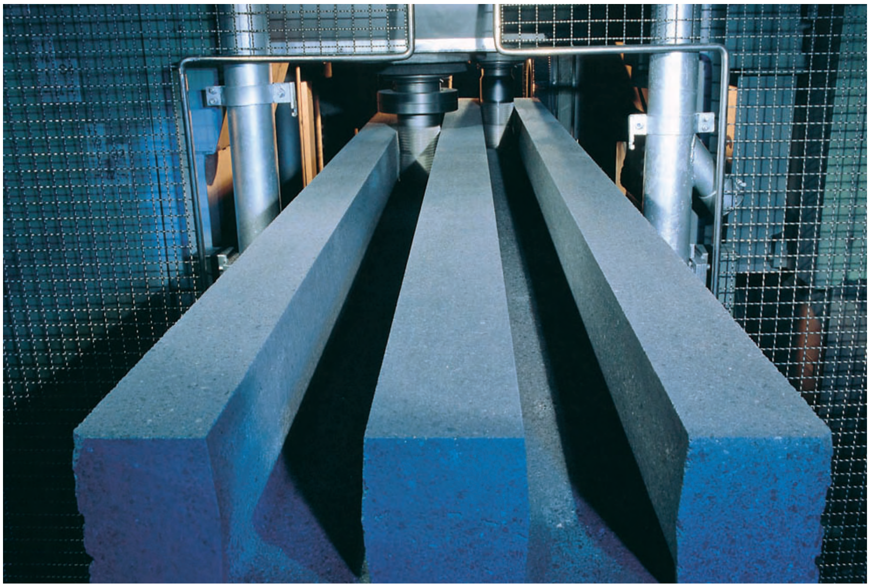
First of all, you've got to have *reactor vessels.* Well, that takes heavy steel. There's heavy steel capability here in the U.S. The steel needs to be rolled, and then some of the fittings need to be machined. There's plenty of machining capability here for that purpose.

Some of the big light water reactors require forgings, and these can only be made in Japan. But I think if we make ours the right size, we'll be able to produce them in a variety of places around the world, rather than using the tremendously expensive forgings.

Question: Right now in Japan, I think if they gear up they can only do nine a year, so that's not exactly mass production.

United Steelworkers

Inside a steel rolling mill, where slabs of steel are transformed into plates, sheets, and strips. Reactor vessels for the modular HTR can make use of heavy rolled steel, instead of the more expensive forgings needed for larger nuclear reactors.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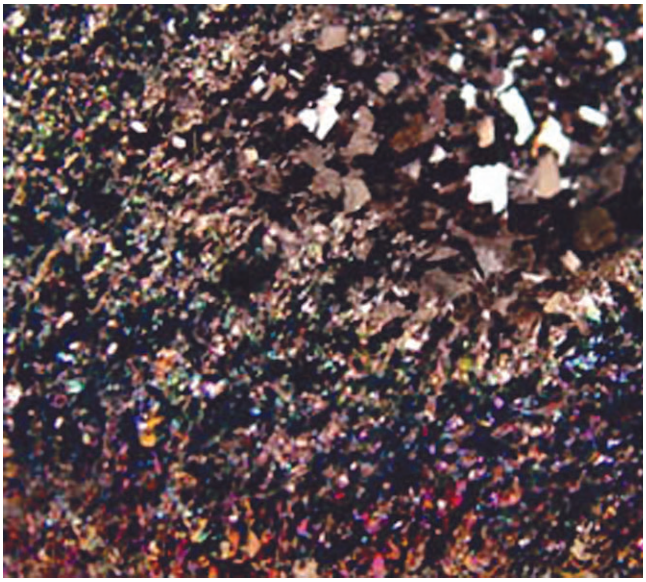
Nuclear-grade graphite is required for the fuel blocks and reflector blocks of the GT-MHR, and the United States has the manufacturing capacity for this. Here, machining of a large cross-section graphite block for use in electrolysis cells.

No, and so you have to look at a way of avoiding those forgings, and I think machined steel plate is the way to do that. Keep in mind that the characteristics of the forgings or steel plates should be different between a water reactor and a gas reactor: A water reactor cannot sustain a leak, because if you lose water as a coolant, you can have a meltdown. But in the gas reactor you cannot have a meltdown, because of its inherent safety.

So I think there's a production capability for the vessels, with a combination of rolled steel and steel plates that are machined.


A close-up of silicon carbide, used in coating the TRISO (tristructural-isotropic) fuel particles for the HTR.

Then you go to the *graphite reflectors.* There's plenty of capacity in this country to produce nuclear-grade graphite. It's very pure and it can't burn. The industry has plenty of capability for turning that carbon into something useful, namely *reflector blocks* for the reactor, and also the *fuel blocks.* So, that's a matter of mobilizing the resources that are already out there to produce carbon logs. They have to be machined, and there is plenty of machining capacity for that.

Then you get to the *fuel.* There are all kinds of places that you can make fuel. The tiny ceramic fuel particles have to be produced in great quantity because they are about the size of a grain of sand. But the processes for doing that have been around for many years. We produced fuel at our site in San Diego many years ago in huge quantities. And between the nuclear fuel manufacturers around and the national laboratories, there are enough places where you could produce the fuel. Obviously, the fuel needs to be tested, and the quality needs to be controlled rigorously, but we have almost 50 years of experience now with ceramic-coated TRISO fuel particles, and that's a darn good base from which to operate.

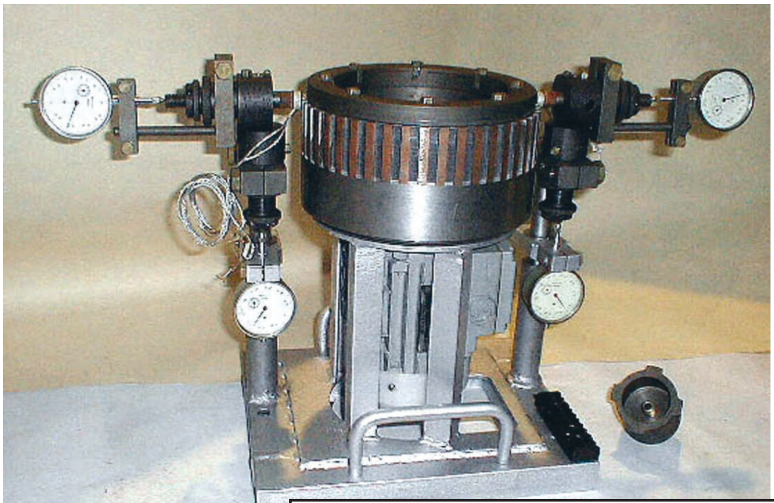
Then you go to things like *control rods,* which are very straightforward. The gas reactor can shut itself down automatically even without the control rods, because of the negative temperature coefficient, which means that if the reactor heats up over a certain point, it will shut itself down. The control rods are just a simple mechanical device.

And then you get to the *power conversion module,* the turbine. You can think of it as a jet engine, which instead of having a big fan on the front, it has a generator. That turbine operates at lower temperatures, lower speeds, and lower stresses, and far, far fewer cycles (the things that sometimes wear out engines) than jet engines do. And also they are not subject to weight sensitivities as jet engines in airplanes are.

So it's a relatively unchallenging use of turbine technologies to produce turbines for high-temperature reactors. The engineering codes for designing the turbines are well established, as are production techniques.

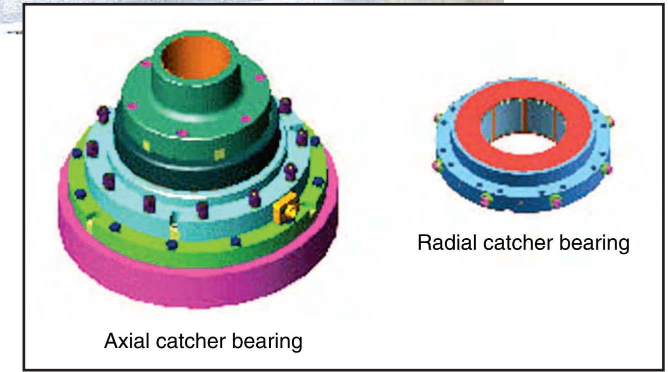
The exercise then is to build a turbine that takes a hot gas, which turns the turbine, and that is attached to the generator. On the other end of the jet engine is the compressors. These compress the helium gas, and then send it back on through the reactor for another load of heat energy—in a continuous cycle.

When you ask the turbine manufacturers if there's high risk in that part of the power conversion module, they say, "No, there's very low risk." The turbine guys say that there may be risk in the reactor design, but not in the power conversion module." By



General Atomics

Electromagnetic bearings on a test rig. Because there is no friction, there is almost no wear on these bearings. Inset is a drawing of the catcher bearing used with the electromagnetic bearing in the unlikely case of an electricity outage.



General Atomics

contrast, our reactor guys, who have been working with the reactors for almost 50 years, say, “Well, no, the reactor isn’t risky at all, after all the work we’ve done over these 50 years, but we don’t know about the power conversion module.”

Obviously, you have to form a team that has all the necessary disciplines to deal not only with the reactor, but with the power conversion module.

And when you get into the capability to build the turbine, there is Rolls Royce, General Electric, and other turbine manufacturers. There’s plenty of capability out there to do the rotating machinery.

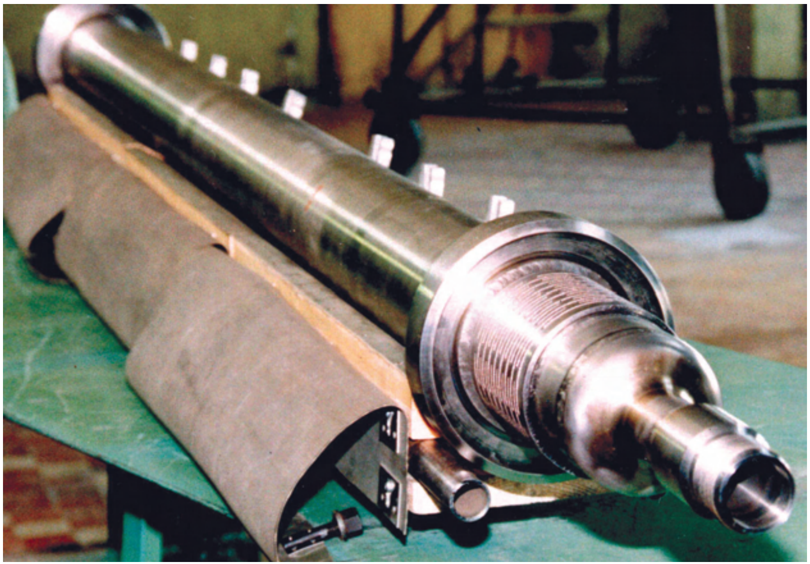
A critical element in the power conversion module is the *bearings* for the turbine. Magnetic bearings are a state-of-the-art bearing system, which was not available 20 years ago, but are in common use today, particularly in gas-pumping booster stations. Magnetic bearings are a far better solution than the oil-lubricated bearings that we used in Peach Bottom 1 [the high-temperature reactor in Pennsylvania in the 1960s], which worked just fine, and better than the water-lubricated bearings that we used in the circulation pump in Fort St. Vrain [the Colorado HTR which operated 1976-1989], which worked very poorly.

The Achilles’ heel at Fort St. Vrain was the water-lubricated circulation bearings, and we simply don’t have those problems with the magnetic bearings. Magnetic bearings are a very elegant technical solution for bearings, just like the turbine itself. Magnetic bearings have almost no wear, because there’s no friction.

The art in using magnetic bearings is having a *catcher system* in case the electricity goes off, for any reason. Of course, that’s extremely remote, because you have back-up batteries, and a back-up source of electricity. But even in the case where there was a total loss of electricity, the catcher bearing solution is something that’s very susceptible to good design.

The *generator* is very straightforward. There are all kinds of generators everywhere in the world, so that’s not a problem.

The *recuperators* in the system are just heat exchangers, and the science of heat exchangers has progressed mightily in the last 20-30 years, and so the *plate fin recuperators* are very efficient and relatively inexpensive. They are not susceptible to the problems of the leakage in heat exchangers, because you are just leaking helium to helium, and if you have a small leak, it doesn’t go outside of the system; it remains inside the pressure vessel. It only shows up in a small loss of efficiency.



General Atomics

A recuperator, the type of heat exchanger used in the GT-MHR, is highly efficient, compact, and relatively inexpensive.

So you take all these technical aspects, which some people might think of as challenges, and you examine them item by item, and you see that the industrial infrastructure is there, the technology is there, and it's just a matter of matching the industrial infrastructure and the technology to the money to get a prototype built.

And once a prototype is built, and it has proven its reliability, then people will look back and say, "Gee, this is obviously a much better technical solution; why didn't we do this years ago?"

Question: It sounds like the manufacturing capability is there, at least in concept, and some of it is operating already in the U.S. and elsewhere. But we're missing that crucial element of *political will* here, and we need that to get this done.

That's true. But here the gas reactors have real advantages. First of all, I think it's much easier politically to deal with modules of 100 megawatts, rather than reactors of 1,200 megawatts.

Number two: it is the safety characteristics that any community can get their arms around and understand. A high-school physics class can do the calculations, and they can see that you simply can't get to temperatures that can fail the fuel, so you can't have a meltdown and you don't need an evacuation area, as some reactors do. So, if there's nothing to evacuate, you don't need an evacuation zone, and they say, "That's the kind of reactor we would like to see. And because it assures low-cost electricity to our communities and factories, and a good industrial capability, we look at all the alternatives, and see that this is a better alternative than coal or oil, or even than other nuclear."

American people are smart, and if all the facts are laid out to them, and they can see that this really is a different kind of physics that governs these reactors, then they say, "Yes, this is better than the alternatives."

We all know that we need energy. Energy is what advances civilization and living standards, and this looks like the best source of energy there is. Even horses cause a certain amount of pollution.

Question: Quite a lot, if that's all you have for transportation.... I think other countries, especially in the developing sector, are particularly interested in this reactor, because it can accommodate to a smaller power grid, and be added onto as the grid increases.

That's very important, and obviously that is a much better solution.

Also, because of the modularity, maintenance is easier. All reactors require some maintenance. Obviously if you have a 1,200-megawatt reactor, and you shut it down for maintenance, you've got to replace it with 1,200 megawatts from something else. In the case of a modular reactor, any place that you have a bunch of them, you can just shut them down for maintenance one by one, and the amount of power that you're losing is so small, that you don't have to have a source of back-up power. That is a significant factor any place you put them, but particularly in small countries where they don't have a grid where they can bring other power in.

It's a far better way to handle the electricity load of a smaller country. It's far better because you're not dealing with a safety equation which absolutely demands that everything be perfect all the time, and so you can see this kind of technology being employed in Third World countries where you probably wouldn't want to have a large light water reactor.

Question: Well, a large reactor would overwhelm the grid of most of those countries.... You mentioned at the HTR press conference in Washington that you thought we could be producing 60,000 of these reactors, and I wasn't shocked by that number, because we've estimated that the world will need 6,000 reactors of 1,000-megawatt equivalent by the year 2050, just to keep up with the growth in electricity demand. So, how do we get this going?

We simply have to build a demonstration reactor. And then once it is demonstrated, and once people understand that it's real, and they see the economics of it, and see the safety of it, then there will be just overwhelming demand for it. That's the kind of challenge or problem that every manufacturer loves to see. It's a lot easier to produce things in quantity, than it is by single units.

So, getting the money matched with the technical capability and getting the first one built is what it's all about.

Question: There is a demonstration reactor being built, in South Africa, of the PBMR pebble bed variety, so it would make sense if here, under the NGNP, the Next Generation Nuclear Plant, we go with the GT-MHR type of high-temperature reactor. But, NGNP is a very "slow boat" at the moment.

I agree. NGNP would be a very good thing to do. I think that this technology is ripe for the private sector to take it up and do it....

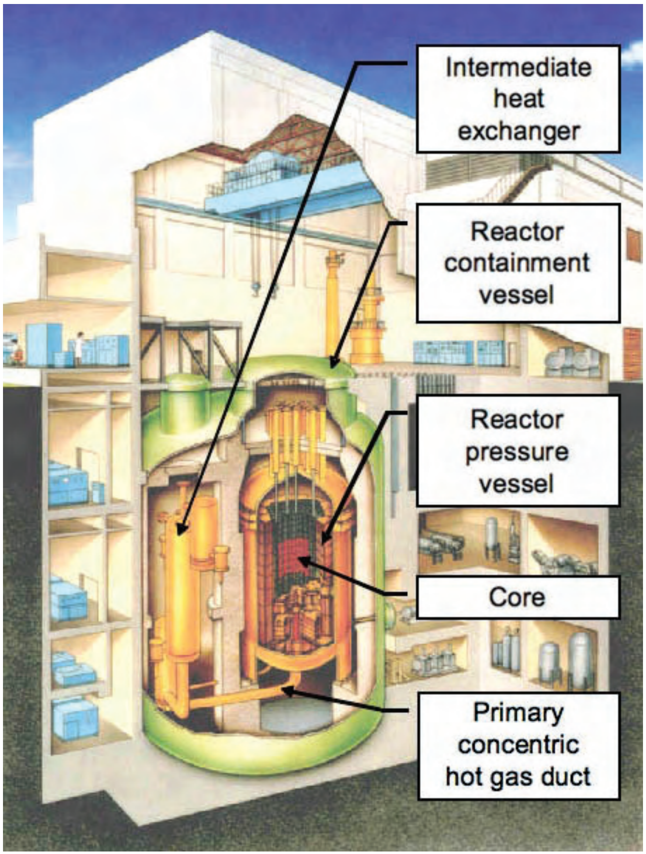
Question: What about Russia? You have an engineering program going with the Russians on the GT-MHR. Can they put any funding into it, in terms of building a prototype there?

The Russians have been collaborating with us for quite some time, in work on a plutonium disposition program [burning up weapons plutonium], which everybody wants to see happen. And the Russians do a superb job of designing and engineering and the physics. They have a good background in this technology. So I think collaboration with the Russians on this could be very real, and has good potential.

The demand is great enough, so that there should be a lot of participants in this kind of program.

Question: The Russians seem to be moving faster in terms of putting new reactors into motion. Of course, they are building industrial-size conventional reactors and fast reactors.

That is true, and exactly what their rate of speed will be as



Japan Atomic Energy Agency

Schematic of the HTTR, Japan's 30-megawatt high-temperature demonstration reactor, which has a prismatic block core.

Japan Atomic Energy Agency

Sintering fuel particles for Japan's HTTR at the Nuclear Fuel Industries, Ltd.

they deal with the lower price of oil, I don't know. The Russians have their own economic problems right now. We have found the Russians to be very good partners in the plutonium disposition program, and that could very easily be converted to a development of a civilian power reactor.

Question: What's the estimated cost of the first reactor, the demonstration reactor, and what would the cost be when you're in mass production?

I believe that the first module could be built for between $600 million and $1 billion. That's my estimate. There are some estimates that are higher, but I think that when you apply manufacturing disciplines to it, and keep things simple, that would probably be a realistic number.

When you get into mass production and come down the learning curve, I think you're looking at less than $2,000 per kilowatt, or about $200 million for a 100-megawatt reactor. Right at the moment, that's actually a lot better than the big light water reactors. So, at that kind of a rate, you really have something that is very economical.

The other thing that the world is going to see is more electric vehicles, and this kind of reactor would be an ideal way of producing electricity to power electric vehicles. Essentially, you could fill your electric tank at home at night for the equivalent of 75 cents per gallon; that's really attractive. Many people who are now paying $3 to $4 per gallon would be overjoyed to be able to charge their cars at night for 75 cents per gallon of gas equivalent.

Question: It's also very convenient. But you have to have that electric power grid.

Yes, and you have to have that off-peak power—that's between 11 PM at night and, say, 5 AM. With nuclear plants, you don't want to shut them down. It makes sense to sell off-peak power at a lower rate, particularly to charge electric cars.

Question: I think the problem we face now in this time of financial collapse is that we need a Franklin Roosevelt approach.... And a critical part of this is building nuclear plants. You really don't have a future without nuclear.

That's right: Modern industrial societies need power, lots of it. Solar will come along; wind can provide a little bit. But the heavy lifting can only be done by hydrocarbons or nuclear.

Question: And we want to save the hydrocarbons for other uses, not just burning them up. Nuclear is an optimistic way to look at how we can build ourselves out of this collapse.

Yes. It's basic production, not paper streams of profit. It's adding basic energy for production. Building such plants would put a lot of people to work. It would obviously do good things for the construction industry. It would have a huge effect throughout the economy to have a major surge in building these plants, and it would save the $7 billion a day that has been going from the industrial world to the oil producers. That was the figure at the time that oil was at $120 a barrel, so it's less than that now. But even so, there's a huge transfer of wealth to the oil-producing countries. HTRs would dramatically change that.

I think I told you my theory for what the potential of this is. Right now we get 20 percent of our electricity, but only 8 percent of our *total* energy from nuclear. If we go to the French example of producing 80 percent of power with nuclear, that would raise us from 8 to 32 percent of our total energy, just by itself. That would create a huge difference in our oil consumption and natural gas imports.

Then, if you assume that we could provide half of the transportation fuel by using electric vehicles, and then half of the process heat from this kind of nuclear—and you know because of the higher temperatures, we can do most process heat applications that the lower-temperature nuclear reactors can't do. So between the French example on electricity, and half of the transportation and half the process heat, you're up to the potential electricity from nuclear to 62 percent. That would almost eliminate our balance of payments problem. To say nothing of getting the price of oil and gas down to realistic levels. It just has a huge effect. The environmental advantages would be another big bonus.

General Atomics

The dedication of the Peach Bottom HTGR Atomic Power Station in 1967. From left, Lee Everett and R.G. Rincliffe, Philadelphia Electric Co.; Atomic Energy Commission Chairman Glenn Seaborg; and John Kemper, Philadelphia Electric Co.

Question: I think there are also the educational and cultural effects of going nuclear, because when you have a society moving forward like that, it gives kids a future. Now what do they have—training to run a windmill? We're going backwards.

It could give a lift everywhere. Right now we're mortgaging our future, buying all that oil, and the HTR is a real alternative.

Question: We could be producing hydrogen too, as a fuel.

Yes, that comes next, and that has significant potential. I think in the short term, the electricity for vehicular transportation makes sense. You already have the electrical grid for distribution.

People could see that instead of sending all that money to oil-producing countries, we could keep that money inside this country. Nuclear has no pollution, as with burning hydrocarbons. That's a better way of doing things. So what's the negative here? The answer is *inertia*! We've got to get it done!

Question: I have an historical question now. When did General Atomics get involved with the high temperature reactor?

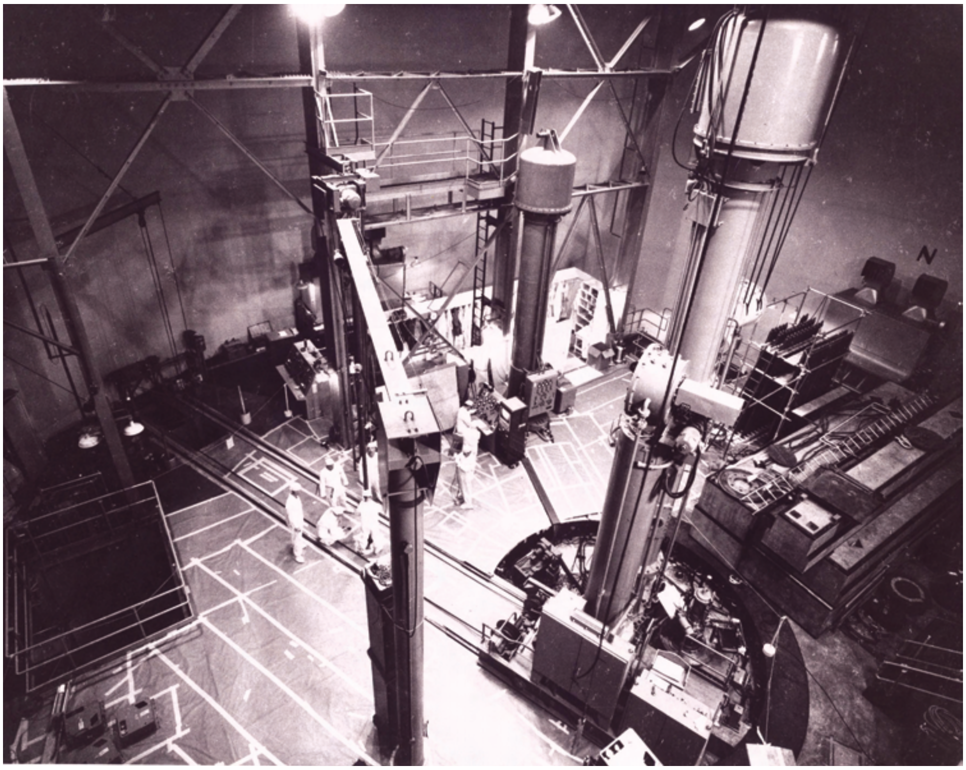
It was about 50 years ago. First of all, General Atomics was founded for the peaceful use of nuclear energy. It was back in the Eisenhower Atoms for Peace era, in the middle 1950s. And you had a lot of very smart people, who asked, "What is the best way to do this?" And they said, well, in submarines you obviously need very very high power densities, greater power output per reactor vessel size, because space is at such premium. But for terrestrial applications, the primary criterion should be the ultimate safety. And how do you produce the ultimate safety? You make *ceramic fuel*, not metallic fuel, and you use helium coolant instead of water, because helium is a noble gas and doesn't corrode.

Of course, back in those days we were still using a Rankine cycle, and it wasn't until the late '80s or maybe early '90s that we decided the technologies were mature enough to do a Brayton cycle. But since that period we've felt that the direct conversion Brayton cycle was the thing to do.

So it's been in that 50-year period that we've been evolving the HTR, and everything has been improved, from the fuel, to the jet engine-like turbines.

We have also had a major setback with the Fort St. Vrain capacity factor. It was never a safely issue; it was a hydromechanical problem, not a nuclear problem. We just screwed up in the design of those lubricator bearings. The water could get into the reactor, and so they would have to shut the reactor down to drain it out. So magnetic bearings are a huge advance.

Technology is a wonderful thing! People invent better things to solve problems. And this is exactly what's happened here. Over this 50-year period, the reactor design has improved dramatically. We've made mistakes, and we've cured them. And now we have something that is so safe, and so economical, and



The General Atomics Reactor operating floor during fuel loading at the prototype Peach Bottom HTGR, 1966. Peach Bottom, operated by the Philadelphia Electric Co. at Peach Bottom, Pennsylvania, successfully supplied power to the grid from 1967 to 1974.

so efficient, and so non-polluting, that its time has come.

Question: Yes, it's overdue. in fact!

Well, you recognize that, and what you're doing is drawing attention to the problem, and you're saying, "Hey, there is an alternative, there is a solution." All too frequently people say, "There's no way to deal with this." Well, there *is* a way to deal with it.

Question: The PBMR people proposed for Africa having regional centers to train engineers and technicians and perhaps a continent-wide regulatory agency. Have you any thoughts on that?

That could be a good solution for Africa. I think that the U.S. is the gold-standard for nuclear licensing, and I think that there's plenty of residual capability in our universities to properly train people, so I don't look at that as a major problem. One of the reasons, again, is that this is such a simple system. You want to have experienced people running them, but if you have people with less experience, they still can't mess them up—in the way human beings messed up at Three Mile Island and Chernobyl. It's just inherently not possible for human beings to cause meltdowns in these modular reactors. So obviously, you do need to train a lot of people, but the U.S. has a great labor force to work with.

And then you need a lot of computer-savvy people running them, and that's sort of everybody in the current generation. Because increasingly Moore's Law is going to govern nuclear control, just like it does everything else, where you have the vastly greater capability to control machines electronically. You also have much better systems for safety.

Question: What's Moore's Law?

Gordon Moore, the visionary head of Intel, many years ago said that computing capability would double every 18 months. Now he said that 20 or 30 years ago. Well, it has worked like clockwork. When you have that kind of a compound improving effect, you have a dramatically increasing capability. That's what's happened in computers, and that's why the world is increasingly driven by computers. And controlling nuclear reactors is just an absolutely ideal application for automated electronic controls.

Question: But you still need that human element.

You still will have that human element. You enable the human beings to do a much better job. It's like flying an airplane, which I know something about. Right now, because of the electronics that Moore's law allows, it's almost impossible for a pilot to lose what we call situational awareness, where they become confused and they don't know exactly what's going on, or where they are. These advanced electronic systems make everything dramatically easier and therefore much safer. And that's one of the reasons you're seeing such an improvement in aircraft operations, and the same thing can be done with reactors.

Question: I wish that there were a similar "law" about mass production of nuclear reactors. . . .

Well, you don't have Moore's law in all areas of production, but you do have the benefit of it. Since there's a lot of electronics in any sophisticated power plant, you get a lot of benefits from the miniaturization, the redundancy, all of the advantages of modern computing, so that's a big reason why it makes sense to have *modular* reactors, because you can have a standard set of electrical controls, and the price of those controls further reduces the price of reactor modules and their operation.

INTERVIEW: JACO KRIEK

South Africa's PBMR Is Moving Forward!

Marjorie Hecht

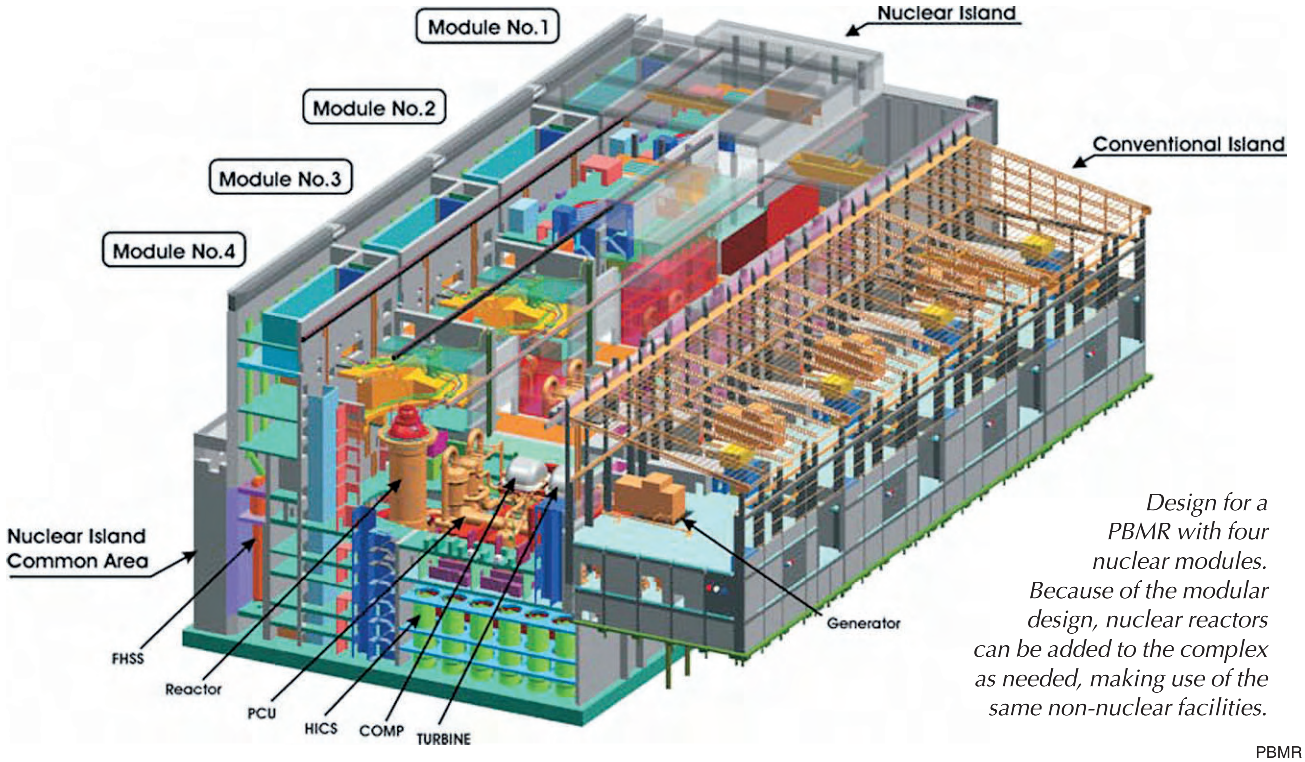
Jaco Kriek is CEO of the Pebble Bed Modular Reactor (Pty) Ltd. in South Africa. He was born in South Africa, Kwa-Zulu Natal, in a town called Vryheid and raised on a game farm bordering the Itala Game reserve. Before joining PBMR in 2004, he was executive vice president of South Africa's Industrial Development Coporation, responsible for mega-projects, including the PBMR, the Mozal Aluminum Smelter, and others. He was interviewed in Washington, D.C., by Marjorie Mazel Hecht on Sept. 29, 2008.

> ***"PBMR is one of the few engineering and science megaprojects South Africa has. We should not waste that opportunity. It's an opportunity in a lifetime for a developing country."***

Question: To me the PBMR represents optimism, not just for South Africa but for the whole continent. I see both the PBMR and the General Atomics GT-MHR as the "workhorses" for what we need for the future.

How do you view the PBMR and its role in terms of transforming South Africa—its economy, its industries, and it workforce?

I think the impact and the potential for gas reactors has been kept alive by PBMR for many years, at a time when nobody wanted to touch it, and nobody was interested in nuclear. Now there is a nuclear revival, and you see a lot of others coming along, that were in the business many years ago. We are not just a small local entity. Already South Africa has created a nuclear industry, although it's still young. We have the U.S. Nuclear Regulatory Commission coming to our regulator to learn how our regulatory licensing is coming along. There was a visit a few weeks ago, a delegation of about 15 people from the NRC, visiting our test facilities. And we've got an ASME workshop next week—the American Society of Mechanical Engineers—because our design is based on ASME standards, and we had to make some additions to the ASME codes and standards—ASME Plus. So ASME is engaged with our regulator.



Design for a PBMR with four nuclear modules. Because of the modular design, nuclear reactors can be added to the complex as needed, making use of the same non-nuclear facilities.

PBMR

In South Africa, we've kept the nuclear idea alive—in public opinion—and therefore when the state utility Eskom just announced that they were going to build a number of large reactors, there was no outcry. The country's citizens almost have an attitude of "We knew it was coming."

When you talk about local industry: we are now busy with about five local companies, to get them ASME accreditation, so that they can manufacture nuclear-grade components for us. We have agreements now with six universities, and we're increasing the number, to include nuclear engineering as a subject. Last year was the first year that two nuclear engineers qualified for PBMR bursaries. In addition, we have research projects with those six universities.

PBMR

The PBMR Helium Test Facility at Pelindaba is testing many of the plant components in a helium environment. The non-nuclear facility is designed to test helium at the high temperatures and pressures that will be experienced in the Pebble Bed Modular Reactor.

And we have created the Nuclear Industry Association of South Africa. Areva, Westinghouse, Mitsubishi Heavy Industries, and others—Eskom, Uranium One, Necsa—are members now. It's grown tremendously, and all the big local companies have joined. Its purpose is really to consolidate all the initiatives—education, regulatory issues, manufacturing, licensing, industrial capacity, government liaison, policy issues.

So PBMR is a substantial local industry. We have over 800 people locally employed, and worldwide we probably have 1,800 people involved in the PBMR program—suppliers, universities, and in departments of government.

Question: You are producing the first of a planned series of a new kind of reactor. What stage are you at now?

We have basically had to handle a number of challenges. This is the first time South Africa is licensing a nuclear reactor. It's a first-of-a-kind reactor. We've got the issues of conventional PWR [pressurized water reactor] safety philosophies, and we measure accordingly. This is a new concept, with new characteristics—inherent safe characteristics, meltdown proof. It's different, and for us, we have to justify on paper that it's different, and that the regulator should accept what you say on behalf of the public that it's safe, without having a reactor built. Obviously there have been other similar reactors. But the regulator wants to see what you're going to do, how you're going to operate it safely. That was the challenge for us.

Because South Africa didn't have a nuclear industry or a nuclear policy, the government didn't really know how to handle this. Remember, it was originally Eskom that started this initiative.

So, we at PBMR were a bit like a young elephant bull. We've got a lot of elephants in South Africa, and they relocate them. But what they found is that if you relocate only the youngsters, they have no discipline. They go wild, and they actually attack rhinos, and cars. The matriarch is the one who imposes and keeps discipline. So we were without a "matriarch"! And therefore, we made mistakes with our regulator—lack of respect, let's say for the nuclear safety culture, for the regulatory requirements, for the customer.

But I think that the "matriarchs" that we got involved, for example, Westinghouse, IAEA [International Atomic Energy Agency], INPO [Institute of Nuclear Power Operations], to help us, and a lot of work inside PBMR, helped us to understand and to really get a nuclear culture. We were a company that was put together by people from the arms industry, utilities, and some from the old Atomic Energy Corporation of South Africa (currently Necsa). So, in the arms industry, you build a cannon and you test it. It's a different culture.

With nuclear, the knowledge and expertise are there, but it's how you do it, the paperwork, the procedures to follow, So those were challenges. And I think in hindsight, the disadvantage was that we were not part, for example, of Areva or Westinghouse. We were not part of a "mothership" that looks after you—people, processes, funding. We were created from scratch. Now the benefit is, we've got a unique culture, a young company. . . .

Question: New ideas. . .

Exactly. So that's the benefit. But it was a rough grinding to get to where we are. And sometimes people say, "Why did it take so long?"

First of all, we had to create a company, and build two projects. Even for Areva, building the conventional Olkiluoto reactor in Finland, this is challenging—with their stop work or-

PBMR

Wildebeest and zebra grazing near the Koeberg nuclear site, where Eskom, the state utility, operates two 900-megawatt pressurized-water nuclear reactors, the only nuclear reactors on the continent. The PBMR demonstration reactor will be built near here. Koeberg is on the coast, near Cape Town.

ders, etc.

So now, when you say PBMR, they assume there's a company, an order department, a licensing department, risk management, finance—that all those things are in place, at the same time that you're running with the technical aspects.

And now the latest status: We will start to produce graphite at SGL Carbon in Germany in the next month or so. This is for the core structure, the ceramics.

That was a breakthrough for us, because there was no benchmark for the quality of graphite required, no ASME standards. So we had to develop our own criteria and specifications that the regulator would accept. This was tough. But now that has been accepted, and we have a machining facility ready where these big one-ton blocks of graphite will be cut and machined for the core structure.

We also got approval from the regulator to start the welding for the pressure vessel; we've got the big shells, about 900 tons of big shells.

Then on the forgings for the core barrel. Some of the pieces have been forged, and we're now racing to get the welding for that done.

For the turbine: We want to start forgings for the turbine casings and we want to start to make the blades.

So, on the long-lead items there's been a lot of progress, but it's been a long process.

Question: When will you start to build the demonstration reactor?

We want to go on site by early next year, for the early work, the non-nuclear construction. And then in 2010, we want to start the nuclear construction. This is subject to our getting a nuclear construction license and a successful regulatory decision on the EIA, Environmental Impact Assessment.

We are starting public meetings now in the next few weeks, and hope to conclude those by the end of the year.

We hope, and we are confident—but it's not in our hands—that we will get a positive decision in the EIA by the second quarter of 2009. Then we've allowed time for appeals and legal processes to conclude, and we hope by the end of next year that we have a decision from an environmental point of view that will allow us to go to site.

Now we also have to still convince the nuclear regulator that we can go to site, because there are certain issues in the Nuclear Act—One thing I should mention is that our Nuclear Act was not designed for new builds. It was put in place after the Koeberg Nuclear Plant was built, so it was designed to *maintain* nuclear facilities, not to build new ones. If there is an issue at Koeberg, the regulator does not shut it down; they will say, "I want you to improve on this or that." But we can't start to build until all the issues are resolved to the regulator's satisfaction.

It's a different philosophy.

Question: How is your regulatory agency put together? Is it appointed by the Parliament?

Yes, it reports to the Department of Minerals and Energy, more or less the same as the U.S. Nuclear Regulatory Commission. It's a board that's appointed by the Minister, so it is an organ of state. And also a lot of work has been done by our self capacity for cooperation, like the NRC. The National Nuclear Regulator, or NNR is part of MDEP, the Multilateral Design Evaluation Panel for regulators. When there is a new design, like PBMR, the regulators cooperate. So the NRC and the NNR cooperate on PBMR.

Question: What will be the effect of the change in government for the PBMR? Do you anticipate a lot of changes?

I don't think so. I don't want to sound arrogant or blasé about it, but we've done a lot of work for the transition. It's still the ANC [Africa National Congress] that is in power, not a new party, so the policies on nuclear, on the PBMR, should stay the same. The next ANC conference will be only in 2012.

From the work that we've done, PBMR is one of the few engineering and science megaprojects South Africa has. We should not waste that opportunity. It's an opportunity in a lifetime for a developing country. SASOL [South African oil from coal company] was another example, and there are very few of those companies in South Africa that can play on the global stage.

As a country, South Africa is way above its weight division in terms of what we're doing. But the circumstances were just there—we were in the right place at the right time to get this technology and take it further.

So, I don't think we'll see changes. Obviously for a developing country there are lots of requirements on funding: infrastructure, social welfare, job creation. But what we're saying is that there's a very direct link between science and engineering projects and anti-poverty measures. Science helps with antipoverty. It helps raise the standard of living for people.

Question: Traditionally, you need a science driver, if your economy is going to grow. A lot of people don't understand that.

Exactly. I've gone around to all the universities, to talk to the vice chancellors, to get them to cooperate with us, saying, "You need to help us to make this link more visible, and clarify it, and explain it. This is something that you should add into your communication and education about science and engineering."

PBMR is a good example because of the spin-offs. For example, we have the fastest computer in the Southern Hemisphere to work with our modeling and to test PBMR systems and equipment. These computers produce models in the *virtual world* that accurately predict and analyze the impact of the strains and stresses the demonstration plant will be subjected to when it goes into operation in the *real world*. This is totally different from nuclear—it's a different field, but the university can now have students and train them in it. Materials, measuring temperature in the core, these are not nuclear, but all these technologies and research are around our technology. And there are many applications. Flownex, for example, is a code that was designed for PBMR, and is now being used by SASOL in other areas.

This satellite view of the African continent at night gives a striking picture of the lack of electricity. Although the continent has 12 percent of the world's population, Africa accounts for only 2 percent of the world's energy consumption. More than half of Africa's electricity is produced and consumed by South Africa.

And companies were established because of PBMR that are now servicing the economy in other areas.

It's an educational process, that we now spend a lot of time on. We have to continue this with the public, because those people who can't see the link, will claim that we are a "white elephant." That's the last thing we are. We're an asset to the country, a pool of expertise and skills.

Question: The country really has no future without nuclear. You have blackouts now with the power supply. You have enormous unemployment.

And if you think there's a magic way of getting out of that, without development, without research—nothing comes for free. You have to invest, if you want to get something out for the economy.

Question: But it has to be real, productive investment, not paper.

Yes—the taxpayer gets a third of that money back that is invested in these projects; it's spent on the people.

So, really, in my mind, one thing that has happened that I think is really positive, and maybe not noticed yet by the international community (maybe it has been, but I really don't see it) is that here in an African country: the President is asked to resign, and constitutional processes are followed, legal processes, and there is no violence. The next President is appointed three days later. The cabinet is reshuffled, new cabinet ministers are appointed, and life goes on.

It's interesting, I think we're in good company, because your President is about to change!

But unfortunately, because of the African connotation, people think that if there's a change, it's going to be another Kenya or Zimbabwe. I think South Africa, the South African market, the South African economy is just too strong, and I think it's been demonstrated that we've started to mature as a democracy, which is very positive.

PBMR

South African pioneers of the pebble bed technology. From left, Dave Nicholls, first CEO of the Pebble Bed Modular Reactor (Pty) Ltd. (now with Eskom), Dr. Johan Slabber, and Dieter Matzner.

Question: It's positive for the whole continent, and perhaps you can say something about that—the role of the PBMR in transforming all of Africa.

Yes, we're talking to our regulator in fact, we're putting a few people at the University of Pretoria to study nuclear law and specifically to set up regulatory frameworks in other countries.

Question: Many African countries are interested in going nuclear—about 20 of them.

Probably initially we will need an African-wide regulator. It's too expensive, too complex, and probably too risky to allow every country to have its own regulator. I don't want to sound like the U.S., or that we need to control it, but I think Africa needs to do that.

Then you have to make sure that the operators are qualified internationally, that waste issues are handled. But I think the fastest way for Africa to get nuclear is to have a very credible regulator—an African regulator with international operators.

If you look at the African grid, South Africa produces and consumes more than 50 percent of the electric power.

Question: You see that in the satellite map of Africa at night, a dark continent, with just a few spots of light. . . .

Exactly. So if you look at other countries in Africa, some of the grids are 900 megawatts, 1,000 megawatts. To give you an example: I was involved in Mozambique with an aluminum smelter. It's a 1,000-megawatt plant. It uses four times the electricity of Mozambique, just that one project. So these small 165-megawatt PBMR reactors are ideal for these countries.

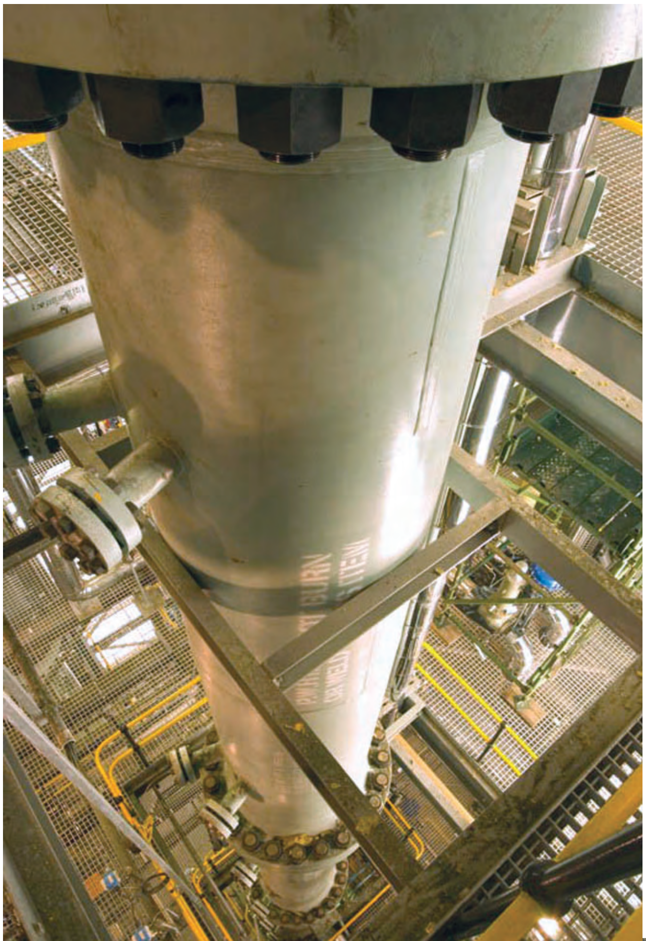
Question: It's a start that can grow with their power grids.

Yes. As somebody said in Mozambique, they use diesel fuel to generate electricity, so cost is not an issue. Even if you think that nuclear will get more expensive, it will never reach the cost of diesel. And then there's the logistics of the diesel fuel.

So it's a challenge for Africa. But South Africa is serious about this. We have a visit to Tunisia next week; they want to understand how they can cooperate with us. Algeria, Morocco, and Libya are also interested in the technology.

Question: These are places with nuclear research reactors, where there already is training of students.

Exactly. So, you'll probably find that we'll cooperate from the South with the North, Northern Africa, and we'll try and see what we can do. Some of these countries want to establish nuclear training schools with South Africa, and invest with PBMR potentially. So I think that there's a lot of potential. And that's just on the extrinsic side.



PBMR

Inside the PBMR Helium Test Facility at Pelindaba.

PBMR

PBMR's Helium Testing Facility at Pelindaba is testing fuel handling, control rods, and secondary shutdown systems.

When a person is inside, it's a very interesting development. If you think about South Africa: We've got gold, we've got iron ore, we've got uranium, we've got thorium, we've got PBMR technology, we've got companies like SASOL—with the technology of producing oil from coal. We don't have much water to generate hydro-electric power. But you put all that together, and you don't have to study too much to say it makes sense for South Africa to go with PBMR.

And we are not just talking about producing energy. We are heavily dependent on imported oil, but we've got all that coal. However, 60 percent of our coal is burned, just to make oil from the coal. SASOL, for example, claims that they can extend our coal reserves by 25 years if they don't have to burn 60 percent of the coal to get the oil out of the other 40 percent.

So I think that combination makes so much sense for us to go with the PBMR.

Now if you look at the energy situation in the world, the oil price, CO_2—and we're not saying anything on the CO_2 situation—but we can see in areas of South Africa where there are coal-fired power stations, it has an effect on the health of people.

Question: The emissions.

Yes. Worldwide, climate change, we're not saying we need PBMR for that. We're saying: Let's get clean energy. Let's get security of energy supply, because coal is not going to last forever. Oil is not going to last forever. So let's use all the energy available to us with as little impact as possible on the environment. That gets us to nuclear. I'm not saying only nuclear, because it's not realistic. We will have to continue to use coal.

We need to build 40,000 megawatts in the next 20 years. It's impossible to just build nuclear stations. We'll just run into trouble. Not just because of cost, but because of time, the schedule required to get licensing, to complete construction. So these are the issues.

Question: Once you get the licensing for the first PBMR, do you have to re-license to mass produce the rest?

Well, obviously then you've got a carbon copy of the technology, and the EIA studies, but you still have to license each site.

Question: But you can put up six or eight plants at the same site?

Yes, sure. The footprint is very small, so you can add a lot of reactors. Again, at this stage, it depends on the customer. For process heat, you're probably talking about two or four units. For electricity, maybe you need more. But maybe you don't, because of the decentralized distribution; maybe a city or an area needs two units.

The distribution has now become an issue—right of way. The transmission lines from the coal-fired power stations in the northern parts of South Africa to the coast in the south are very long (about 1,500 kilometers to Cape Town), and you lose energy on your transmission lines—up to 20 percent of your energy on long transmission distances. At the moment, Cape Town is dependent on the Koeberg nuclear plants, plus the transmission lines.

And the loss of 20 percent during transmission, means that out of every 100 megawatts, only 80 arrive at the end of the line.

Question: So you really need an upgrade of your transmission lines.

It's happening already.

Now, obviously with the big nuclear stations, you're limited to the coast. So location is an issue. We don't have big rivers that we can locate nuclear stations on.

There is hydro—the Congo's Inga project, but it is 4,000 kilometers away. So we can't rely too much on that. Coal is in the north of the country, and your industrialization is on the coast. So that's where the new big nuclear stations will assist.

But the areas where you've got mining activities are far from everything—far from the coal, far from the coast. So there is a good case for the PBMR, [which doesn't need water for coolant].

I don't think there will be many big changes from the new government on this. Affordability will be an issue—it's always an issue. And we're going to have to make as much progress as we can.

Question: I think the government really can't afford *not* to do it. . . .

What about your relationship with the Chinese? China has built a demonstration pebble bed reactor. Are you working with them?

Yes, they have basically taken over the German design, with a 10-megawatt reactor. It's not a commercial size. We are in discussions with them, and I think where we could cooperate is on the issue of licensing and process heat—they have a lot of coal. One of our local companies, SASOL, is extremely involved in China. The Chinese HTR also uses pebble fuel. We will have to establish where we are each in our program, and what the common areas are for cooperation. Fuel, principles of licensing and safety—those are areas we can cooperate in.

We signed a memorandum of understanding with China in 2005; we're actually meeting them tomorrow to explore potential cooperation. . . .

Question: China has invested a lot in Africa—they are building dams and various other big projects. So it seems that they understand the value of getting infrastructure built in the continent.

But they are not as much in South Africa yet. They are in Mozambique, Zimbabwe, Sudan, and some other West African countries. I think in South Africa, because of the economy, most of the reserves are owned by different companies: Anglo-American, BHP Billiton, big international companies. So I think maybe the space for the Chinese is less. In other countries, like Zimbabwe, the international companies pulled out so there is more access for China. Same with Mozambique.

You know with agriculture in Mozambique and Zimbabwe, they have the potential to feed the whole African continent!

Question: Yes, they could. And Sudan has huge agricultural potential too.

Yes, if they could just get their act together. But one of the issues is distribution, logistics. Another issue is that they are not allowed to export their goods. The duties on their exports are high. The domestic market is small—they have too much for that area. So that's always an issue for small economies.

It also applies to South Africa. If we have a big project like a steel plant or an aluminum smelter, we have to export. Our local consumption is too small. But you have to build a big plant; otherwise it doesn't make economic sense.

Question: My interest for many years has been with nuclear, and with developing the world. And we—the Lyndon LaRouche movement—have proposed the Eurasian Land-Bridge, which would extend from the east coast of China all the way to Rotterdam, to open up the interior of Eurasia for development, new cities and industries. We see the PBMR and GT-MHR as the work-horse reactors for that. We would start with nuclear there, and there is a lot of support for this program.

I think one thing that is not yet taking place is international cooperation. Commercially you're trying to protect your IP [intellectual property] and your lead in the market, but I think that is why it is difficult for companies to cooperate. But *countries* should cooperate.

And now there's a draft agreement between South Africa and the United States on research on new advanced technologies, like PBMR, and with the NGNP, Next Generation Nuclear Plant, we're participating in that program, and with the NRC, ASME. With the U.S., there is a lot of cooperation. But we're not at the point yet where we can share the funding of these projects, to make it easier.

Unfortunately, it looks like there's going to be duplication. In the U.S., they want to build their reactor; we are going to build our reactor; China is going to build its reactor. Japan, etc. And the first-of-a-kind costs involved in building these first ones is so expensive. If we could share that, then it would make it much easier to build the reactor. Then it would be just the materials.

Test facilities—we spent $100 million on test facilities, which I think in hindsight was good. We've learned a lot, and gained a lot of experience from our test facilities. And the U.S. NRC is now saying that they want to do some of their tests in our facilities.

Question: Of course the U.S. shut down its test facility—the fully operational Fast Flux Test Facility. That was really stupid. So, in this case, you are providing leadership to the United

Courtesy of Emerson Process Management

Solvent blending at a Sasol plant in South Africa. Sasol produces oil from coal, a process that requires burning 60 percent of the coal to get oil out of the remainign 40 percent. Using the high-temperature process heat of the PBMR would be far more efficient.

States. Because you're moving ahead, and so far you've had government support. I don't think that situation exists in the U.S. in the same way.

We have a least a three-year window of predictable funding, whereas the DOE programs are funded annually.

Question: The DOE is really a dinosaur.

But if you call them dinosaur, ours is older!

Question: What about the George Soros-funded opposition to nuclear in South Africa?

It is sad that foreign companies or rich people try to dictate or influence policy decisions in developing countries, when in their own country, they are going to go nuclear. It's sad that they don't want to allow *us* to do it, I don't know what makes them feel they should spend money on this. Maybe the trust or foundation doesn't even know that the money is spent on this. Their money is so big, and spent all over the world. The funder doesn't always realize the damage they are doing to South Africa, or to other developing countries.

Because what do you want us to do? Do you want us to continue to import nuclear technology and fuel from the U.S., or from wherever else? Why can China, Japan, France, go ahead with nuclear—but foreign money is used in South Africa for anti-nuclear campaigns? It doesn't make sense to me. But unfortunately, that's how life works.

If somebody has got a conscience, they're going to spend their money combatting malaria in Mozambique, for example. I think the anti-nuclear funders don't really appreciate the damage they are doing.

Question: In some cases, I think these groups intend to damage, because they don't want to see the world go nuclear, for population reasons.

But why don't they do it here [in the U.S.]?

Question: Well, they do! They *do* fund anti-nuclear groups here, and there is an opposition to nuclear here. . . .

But they're not very successful here.

Question: On the other hand, we haven't built any new nuclear plants since the 1970s.

I believe that there are now signs that companies will get combined operating licenses to build new plants.

Question: Yes, but it's very slow. And there was a lot of damage done by this funding going into the anti-nuclear groups.

But because you have 104 active plants, you're a lot stronger on the nuclear front. South Africa is really at the beginning, so the damage to us is much bigger. They are planting doubts in the mind of the public and the government. They say it's too expensive; they call us a "white elephant."

You find some people listening to that. They need to balance the books on the funding, and they ask, "Should we do this for the PBMR?" And now someone from the U.S. is saying it's "stupid." Or "why not build windmills from Denmark."

Question: Well, the Danish are putting funds into the anti-nuclear movement in South Africa.

And why? Because they want to see windmills?

Question: They haven't been able to replace any conventional power plants in Denmark, even though they have all those alternative windmills. Because the windmills don't produce enough reliable energy. . . .

On a different subject: What do you plan to do with the used nuclear fuel. Will you reprocess it?

As far as waste is concerned, so far there is just a low-level waste site called Vaalputs, in an area called Namakwaland.

There already is a policy approved that the utility, at the time when they want to store their waste, and empty the pools, they will have to justify whether they want reprocessing, or long-term storage. So the final decision hasn't been taken yet. And it is in the hands of the utility that will do the economic and technical presentations to the government.

Question: The utility being Eskom?

Yes. Now, there's a bit of waste from Pelindaba, at Necsa, the Nuclear Energy Corporation of South Africa, at the moment, is the custodian of the low-level waste. So Vaalputs is the site, but it's only for very low-level waste. None of the spent fuel from Koeberg has been moved there.

I don't think South Africa will ever put up a reprocessing facility; it's too expensive. France, Japan, and eventually the U.S., are going to go in that direction. But we'll always have to send out our spent fuel for reprocessing. I know the French have already made a proposal to Eskom, because the Koeberg station's sister station in France, is already operating on MOX fuel [mixed oxide made from recycled fuel]. So Koeberg, with some adjustments, can also operate on MOX fuel.

And what's interesting on the NGNP, is that there is now research that high temperature reactor fuel can utilize plutonium from the waste of nuclear weapons.

Question: That's what the General Atomics GT-MHR is doing.

Yes, with Russia.

And we are also looking at waste minimization. We want to recycle the graphite. This is a program we're doing with research at one of the universities, and with the European Union, with SGL Carbon, a German company that is producing our graphite for the core structure and for the fuel spheres.

So that's the picture on waste.

Question: How did you get involved in the PBMR?

By accident! I am a chartered accountant. In my previous life I was with the IDC, the Industrial Development Corporation, as the vice president for mega-projects. Steel plants, aluminum plants, all the big projects were under me, and the PBMR was one of them. And then, when Eskom pulled out from the project as the lead investor, the ex-Minister [of Public Enterprises] Alec Erwin, and my chairman, Dr. Alistair Ruiters, asked me if I'd be on a task team to discuss with the Cabinet ministers how we were going to move the project forward. That was in February 2004, and on May 27, 2004, they asked me to head the company.

It's been fascinating. The big mega-projects experience was very useful to me, because thinking big, was not new to me. But nuclear was totally new to me. Now I know it superficially. I like the industry. And the timing was good, because of the nuclear renaissance. In 2004, it was totally quiet. In 2005, also. But in 2006, we had an HTR conference in South Africa, and you could feel that the nuclear industry was coming back.

So PBMR's timing was good. It was a little ahead of its time for this renaissance. Let's say five years or more. But in the last two or three years, that has changed, and there's a lot more interest now.

We're in a unique situation in South Africa. We desperately need energy.

Question: Yes, you've had blackouts and brownouts.

They claim that the blackouts we had in January of this year cost the economy 50 billion rand.

Question: And what you could have done with that. . . .

Exactly. We could have built lots of reactors with that. . . . And Eskom now has to make a decision on its big reactors, between Westinghouse and Areva. The issue is cost. The nuclear renaissance, in my view, has selected the wrong time to start. Capital investment is high. The penalty is a lot more now.

The question is, will electricity get cheaper? And I don't know for the foreseeable future, because if you look at how many reactors are being built or planned, the demand is going to be there, but the supply chain might not keep up with it.

Question: At the press conference this morning, I raised the question that we're in a complete financial collapse. And what we need is 6,000 nuclear reactors to meet demand—the equivalent of 6,000 at 1,000 megawatts; they don't all have to be 1,000 megawatts.

I think if the industry is convinced that it's sustainable, the capacity will come. But even now, Finland [the Olkiluoto reactor] is late. The cost is enormous. In South Africa, the decision has been postponed. Europe is moving slower than people thought. It's slower everywhere. So, I think industry is sitting back and saying, "OK, I'll enjoy this wave of high prices, but I'm not going to expand. I'm going to wait." They were bleeding three years ago.

Question: What they did is increase the capacity of the existing plants, instead of investing in new ones, because it's cheaper for them—in the short term. They are not looking ahead. They need to be investing now.

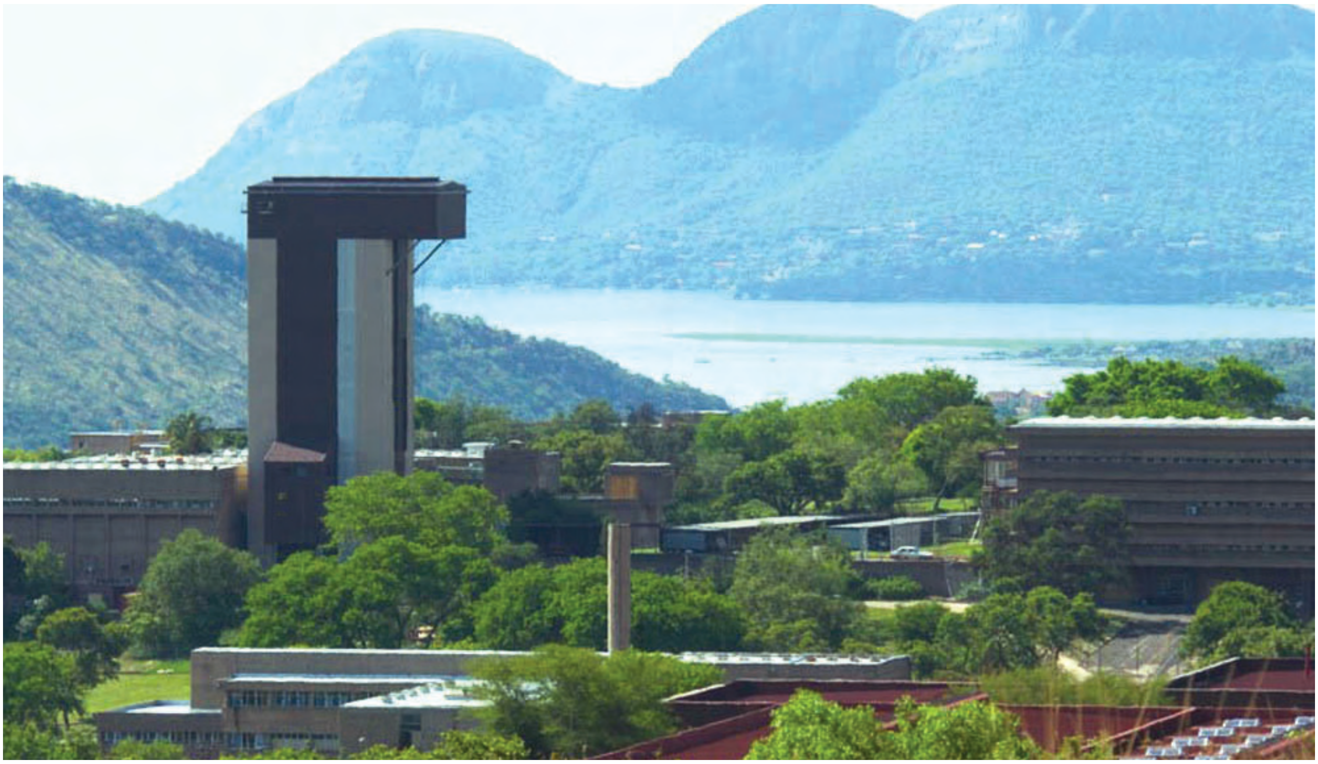
The other question I raised at the press conference is that we really need a new policy, of the sort that Franklin Roosevelt instituted in the Great Depression. The U.S. banking system is collapsing—the $700 billion bailout is not going to do anything for it. It can't—it's a bottomless pit. We have to put these banks into bankruptcy proceedings and start again in an orderly fashion with a New Bretton Woods. I don't see a nuclear renaissance being able to take place unless we have that kind of reorganization.

I think everywhere this is a problem. In South Africa, we've neglected infrastructure—roads, railways, ports, electricity, water.

The problem for us now is in prioritizing funding. You've got real poverty, unemployment, and the unions: When you say, you're going to build a new port, they say, "What for? We need jobs." And this short-term mentality and inability to plan will always try to make this new port look bad. It's big infrastructure, it doesn't create jobs.

But that's absolutely wrong. It's that link, the link between good roads, ports, railway lines, water. . . .

So it's an interesting debate. You also have the element of the government that will try to say to the public, these guys are creating white elephants. "It doesn't create jobs for me so therefore



PBMR

The Pelindaba site of the Helium Test Facility, with the Hartebeespoort Dam in the background. The 43-meter-high facility was built to test the helium blower, valves, heaters, coolers, recuperator, and other components at pressures up to 95 bar and 1,200°C

it can't be good."

Question: Where do they think the new jobs are going to come from, if not from advanced technology?

Unfortunately those who think only in terms of the short term, do not see the long-term picture. For South Africa to continue to import and export, we need new ports. Our ports are full. Meanwhile, our railway lines are bad or not well maintained, so they are using trucks to haul manganese and coal, so that messes up the roads. And we lose lives too.

Question: We had better railways in the early 20th Century than we have now. We need to look at this worldwide, and we need to do what Roosevelt wanted to do, which is to decolonize Africa and all the other colonies, and go with the most advanced technologies, like maglev trains. . . .

The South African rand is one of the most traded currencies of developing countries, and you have to be very careful with your policies, statements, fiscal policies, because things happen fast, and it does constrain you. Because if an analyst somewhere doesn't like what you're doing, then your currency goes. We are vulnerable. I'm not an economist, so I don't understand. . . .

Question: But you do understand that you need a science driver. and that you need to produce real things—you need a physical economy, and not a paper economy.

What a lot of people don't appreciate, is that it's a chicken and egg situation with infrastructure. You need to put the infrastructure there before industry will develop. You can't say to industry, "If you build an aluminum smelter, we'll build you a port." They are not interested. Take, for example, the Coega harbour project near Port Elizabeth on our east coast, which I was involved with on the IDC. "If you build a zinc plant there," we said, "we'll build a port." And the industry said, "No, no, no, show us you're going to build the port first." So, what happened? The zinc plant was cancelled.

And today there is a port, and now everybody's saying "It's a white elephant, it's not used." But Richards Bay is a port that was built 40 years ago. And people were saying then, "It's crazy, there's nothing there." But today it's the busiest port in the Southern Hemisphere.

Question: You need to have vision. You need to think 50 years ahead.

And energy is even longer. For a nuclear plant, you have to look ahead 60 or 80 years. So if we look back, to 1928, you had to make a decision on the nuclear stations we need now! If you make an investment decision, it's a long, long time you're talking about. If you make a wrong decision—that's where we are now. And I'm concerned that because of the cost issues with nuclear, that we're going to continue with coal. And we're going to get sanctions against us. Whether it's right or wrong, that's the reality. It's again one of those things that developed economies will say, "Look what I'm doing for carbon emissions and reduction.

HIGH TEMPERATURE REACTORS 2008

Who's Trying to Strangle the PBMR?

by Gregory Murphy

The American Society of Mechanical Engineers held a conference in Washington, D.C., this Fall to highlight current research on high-temperature gas-cooled nuclear reactors.[1] These are the new generation of supersafe nuclear reactors using tiny fuel particles which each carry its own containment structure.

The Sept. 29-Oct. 1 conference focussed on the positive benefits of nuclear power, and in particular the many advantages for industry and agriculture from the high-temperature process heat that can be produced by these new generation reactors, which include both the pebble bed design, PBMR, and the General Atomics prismatic design, GT-MHR.

Behind the attacks on the PBMR are funds from George Soros (top right) and the Heinrich Böll Foundation (the foundation of the Green Party), and the hired pen of Greenwich University's Steve Thomas (top left). Above, green terrorists in the 1980s attacking a German nuclear plant.

This focus was driven home with real optimism by the Vice Chairman of General Atomics, Linden Blue, in his keynote address. Blue said that the high-temperature gas-cooled reactor's "time has come"; the new reactor will revolutionize the nuclear industry and all other industries as well.

It was a welcome change compared with the current small and narrow thinking of the nuclear industry, which attempts to sell the nuclear renaissance as the best solution to the non-problem of global warming.

The optimism that Linden Blue brought to his keynote carried over throughout the conference, as evidenced in the animated discussions after the conference presentations, in the hallways and the exhibit center (where nuclear companies have display booths). There has been a shift among some of the people in the nuclear industry, away from the "kicked dog" mentality of the past, to a fresh sense of hope, as was shown by the normally reserved German nuclear vendors. They were expressing true happiness at the prospect of Germany returning to a pro-nuclear power stance, as in the past, which they expect to happen some time after the next election.

The Soros/Thomas Factor

Haunting the 2008 conference was the specter of the latest attack on the South African PBMR, part of a negative campaign which has been going on for the past decade. The current attack was launched by a Soros-linked so-called "professor of energy policy" at Britain's Greenwich University, Stephen Thomas. In July 2008, Thomas wrote a white paper titled, "Safety Issues with the South African Pebble Bed Modular Reactor: When Were the Issues Apparent?" in which he cites a July 2008 report from Dr. Rainer Moormann of the Jülich Research Center. Jülich is the site of the first pebble bed test reactor on which the current design is based.

Moormann's report, titled "A Safety Re-Evaluation of the AVR Pebble Bed Reactor Operation and Its Consequences for Future HTR Concepts," was played up by Thomas as a major work of evaluation from the famed Jülich Research Center, which built and operated the AVR pebble bed reactor. In reality, as the conference discussion made clear, the report originated from one disgruntled employee of the institution, Rainer Moormann, who describes himself as a "risk assessment" guy.

In a discussion with this reporter, Thomas gave arguments against the South African PBMR which seemed to be little more

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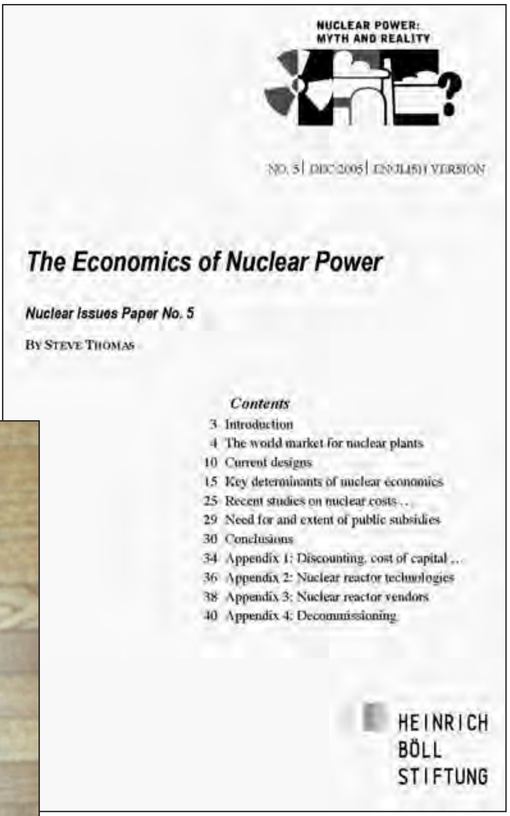
[1] The 4th International Topical Meeting on High Temperature Reactor Technology ("HTR 2008: Beyond the Grid").

The decade-long attack by George Soros on the PBMR has been fronted by green fascist and so-called Professor of Energy Policy, Steve Thomas, of the University of Greenwich's School of Business. In July, Thomas sent his recent white paper, titled, "Safety issues with the South African Pebble Bed Modular Reactor: When Were the Issues Apparent?" to anti-nuclear groups and the European and South African media.

University of Greenwich Public Services International Research Unit



NUCLEAR POWER: MYTH AND REALITY

NO. 5 | DEC 2005 | ENGLISH VERSION

The Economics of Nuclear Power

Nuclear Issues Paper No. 5

By Steve Thomas

Contents

HEINRICH BÖLL STIFTUNG

"No probative value," was the verdict of a South African court on one of Steve Thomas's reports on nuclear energy. Here, the title page from his December 2005 report.

than a thinly disguised racism of the British imperial type. Asked to explain why he opposed the pebble bed reactor, Thomas argued first: Why does South Africa believe that it could operate a high-temperature reactor, given the fact that the major nuclear powers have given up on operating them? (Doesn't Thomas know that it was a South African who did the first-ever heart transplant? Or that Japan and China are both operating demonstration HTRs?)

Thomas continued by saying that the pebble bed and other high temperature reactors have not been proven to be economical. Even if they were, he said, countries around the world would not buy them from a new or novel vendor like the South African PBMR, Ltd., because countries tend to be very conservative and usually go with known vendors.

Is Thomas really saying that because South Africa is a black nation, no one will trust them?

This attack by Thomas is not his first. Back in 2005, Thomas was hired to pen a report attacking the pebble bed for the Soros-funded Legal Resource Center in South Africa. Thomas's report was a key part of the case against PBMR in the legal challenge against the environmental impact study.

The legal challenge was joined by Earth Life Africa, a group set up in the 1980s to be the South African Greenpeace, which attached itself to the anti-apartheid movement to gain support and legitimacy. Earth Life Africa runs a large anti-nuclear campaign, called "Nuclear Power Costs the Earth." This is funded by the Heinrich Böll Foundation in South Africa and the Wallace Global Fund.[2] After the presiding judge read Thomas's report, he ruled that the environmental impact study had to be redone. This has caused PBMR undue delays in building the demonstration plant that was set to begin construction in 2004.[3]

When Thomas was asked by this author why he objected to the South African government being the largest stakeholder in the PBMR, Ltd. project, he said that it was because "public money" was being used on a project that has not gotten off the ground, and there are other uses for that same public money, like "health care and water projects." Of course, Thomas doesn't mention that his "reports" are the reason for the delay in building the pebble bed.

Privatization and Transparency?

Let's now look at where Thomas works: His office is in London, at the University of Greenwich's Public Services International Research Unit. This outfit is funded by Public Services International, a confederation of international trade unions, which includes, in the United States, Andy Stern's Service Employees International (SEIU) and the Teamsters. Yet, Public Services International is a grouping of rabid privatizers. According to its website, the group was very active in the former Soviet bloc during the "shock therapy" era of Jeffery Sachs and George Soros's Open Society Foundation.

Every year, the Public Services International Research Unit releases a resistance-to-privatization index, similar to the corruption index of that nation-state destroyer, Transparency International. With this background, it is laughable for Thomas to claim that public money is being misspent on the pebble bed, and not

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[2] The Böll Foundation is Germany's premier greenie funder.

The Wallace Global Fund is part of the Wallace Genetic Fund that was set up by FDR's Vice President Henry Wallace in 1959. When first established, its mission was to further the legacy of Henry Wallace by helping to develop the world and increase the food supply. But current operations of the Wallace Fund really spit on Wallace's legacy by funding groups that attack modern agriculture and the development of nuclear power, and promote depopulation of the world.

[3] For further details on this story, see Dean Andromidas, "Who's Sabotaging the PBMR?" *21st Century Science & Technology*, Spring-Summer 2006.

Stuart Lewis/EIRNS

Mega-speculator George Soros funds the South African environmentalist groups to further the aims of the British in splintering the continent and cutting its population.

given to health care and water projects, which he and his grouping are looking to steal.

The South African *Cape Times* newspaper picked up Thomas's white paper and promoted its deceptions. *Cape Times* green correspondent Melanie Gosling wrote an article titled "New PBMR Will Fail U.S. Standards," which argued, entirely falsely, that the PBMR would not be certified by the U.S. Nuclear Regulatory Commission because it does not include a secondary containment structure in its design. In fact, the self-containing design of the multilayered fuel particles and the reactor characteristics render a secondary containment structure unnecessary for this type of reactor.

Second, Gosling's claim that the PBMR does not meet U.S. safety standards is entirely bogus. The Nuclear Regulatory Commission has not been formally given the request for a design license by PBMR, and currently the NRC is working in close cooperation with the South African nuclear regulatory group to work out what the safety regulations will be.

The argument for secondary containment was the main alarmist point in the Moormann report, and was also played up by Steve Thomas in his white paper. Sources from PBMR Ltd. whom I questioned at the recent conference, said that they had replied to e-mail questions from Ms. Gosling, but that none of their responses was used, even in part. Gosling's question shows that she doesn't understand the principles behind the pebble bed. Moormann, who understands the basic principle, still maintains that a gas-tight containment is needed for pebble bed reactors. How was this rebutted?

This is what the PBMR spokesmen wrote:

> While containment is an appropriate concept for reactors which use water as a coolant, we believe the best concept for gas-cooled reactors such as the PBMR is to filter the helium (i.e. remove the radioactivity). The radioactivity will therefore be contained, not the coolant. . . . The PBMR confinement concept is by no means inferior to that of a containment structure. It is our view that confinement is the best solution for a gas-cooled reactor, both from a technical and safety point of view. Analyses have shown that confinement will reduce—rather than increase—the risk of radiation releases to the public. It is therefore a safer concept. The PBMR confinement concept allows for the release of extremely well-filtered coolant (helium).

PBMR, Ltd. knew that the specter of the Moormann controvery could have cast a pall over the conference, and their scientists and engineers came prepared to intervene with a prepared safety briefing, both in printed and CD format. PBMR also produced a CD of their presentations countering the Moormann report, which was distributed to the conference.

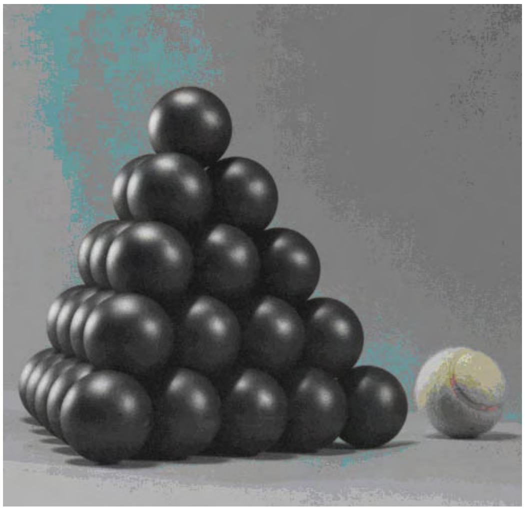
What's Wrong with Moormann's Argument?

Let us now take a look at the source report for Thomas's latest attack, the report by Rainer Moormann. When his paper was issued in July of this year, there was an immediate uproar in the high-temperature reactor community working at the Jülich Research Center, including many internal e-mails attacking the report. In fact, the report is one person's opinion on the data that were accumulated from the 21 years of successful operation of the AVR reactor in Jülich, Germany.

Moormann describes himself as a risk assessment person, and his report shows him to be a person devoted to the precautionary principle: Everything must be shown to be without risk in order for a program or new technology to be brought into use. Moormann's report, however, is based on the 40-year-old design of the AVR. The main concerns he raises are the release of the radioactive isotopes strontium-90 and cesium-137 into the primary coolant loop. Moormann claims in his report that this was caused by the unusually high temperatures at which the AVR core operated. Based on this assumption of these unusually high temperatures, Moormann states that the ability to produce high-temperature process heat, which is a main advantage of the pebble bed, should not have been demonstrated.

Moormann's report is *not* anti-nuclear, as Thomas and the Greens in the media have presented it. His report contains some conclusions that are worth looking at in designing future high-temperature reactors. But his main conclusion, that the pebble bed reactor needs an airtight containment, is just pure alarmism and shows a real failure in his interpretation of the lessons learned at the AVR.

It is to their credit that the organizers of the HTR 2008 confer-



Nukem Technologies

Sample fuel pebbles for the PBMR. Each fuel sphere contains about 15,000 fission fuel kernels. About 450,000 of these pebbles will be loaded into each reactor vessel.

Nukem Technologies

Fuel spheres in production at Nukem Technologies. After the fuel particles are pressed into the core of the fuel spheres, a layer of graphite material is added and the sphere is machined and then carbonized and annealed at 2,000°C. The spheres then go though several quality control tests, including X-rays to check the centricity of the fuel core.

ence invited Dr. Moormann to present his paper there in person, and face his peers. This was the first time, in fact, that this author has seen a real discussion on a controversial paper like Moormann's at a conference. Most often, the author, if invited, gives such a presentation and leaves. To his credit, Moormann took several questions after his presentation and stayed around to discuss his paper with attendees and answer some tough questions about his conclusions.

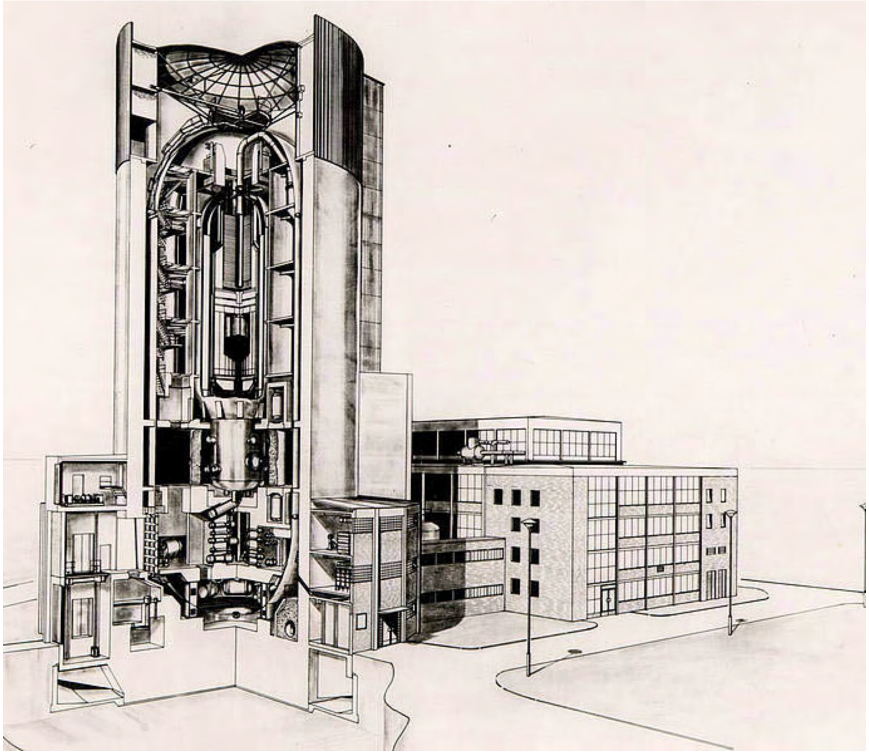
It was exciting to see a real fight about ideas taking place in a nuclear conference, where usually conference attendees just complain and get enraged, but never confront the issue. It is also a good sign for the nuclear industry to show that it is not afraid to confront controversial reports—something the industry has failed to do in the past 30 years.

As part of the general discussion of issues in the Moormann report, there were several other presentations on the data from the experimental AVR. Most of them showed that the majority of the strontium-90 releases happened in the early years of the reactor operation, when poor quality fuel was introduced into the core, and stayed in the core for longer time periods. But, as noted in a presentation by Karl Verfondern, et al. from the Jülich Research Center, titled "Fuel and Fission Products in the Jülich AVR Pebble Bed Reactor," the early fuel was of poor quality and used highly enriched uranium, which was the source of the release of strontium.

In his presentation, Dr. Vernfondern shows that as a better quality of fuel was introduced into the core of the AVR in the mid-1970s, the release of strontium and cesium went down. Most of the strontium activity monitored came from the earlier fuel, as could be demonstated from the 30-year half-life for strontium-90.

Nukem Technologies

The first core loading of the Thorium High Temperature Reactor in Germany, which was constructed in 1983. Both the THTR and the AVR were shut down in 1988 as part of the political reaction in Germany that followed the Chernobyl accident.



Arbeitsgemeinschaft Versuchsreaktor GmbH

Cutaway view of the AVR experimental high-temperature reactor at Jülich, Germany. This was the first HTR to use a pebble bed core, and it operated successfully for more than 20 years, from 1966 to 1988. The AVR demonstrated the high-temperature capability and its safety features, including a safe shutdown with total loss of coolant and no control rods.

Arbeitsgemeinschaft Versuchsreaktor GmbH

Dr. Rudolf Schulten (left) developed the pebble bed concept and built the first prototype, the AVR at Jülich, Germany. Here he is consulting with Dr. Werner Cautius in the AVR control room.

The best rebuttal of Moormann's report came from the scientists and engineers who work with the PBMR. It was masterful in that it judoed the report by showing that, using the exact same AVR data set which Moormann used, their "Dust and Activity Migration and Distribution (DAMD) model" demonstrated (as did most of the other studies) that it was the poor quality of fuel in the beginning of operations of the AVR which was largely responsible for the problem. They also showed that certain core design problems, since recognized, created voids and bypasses in the coolant flows around the pebbles.

One has to remember that the Jülich AVR was a first-of-a-kind reactor; it was the first pebble bed reactor ever built, and operated for 21 years with only minor incidents. In those 21 years of operation, the AVR generated a very valuable data base and there were many engineering lessons learned, which have already had their impact on future design specifications.

One recent development is that with the use of high-temperature fiber optics, it may be possible to monitor the core temperatures of pebble bed reactors. Because of its moving fuel—with pebbles introduced at the top, flowing through, and reintroduced at the top again—it is difficult to precisely monitor the internal temperatures. But that may be solved with the application of engineering principles and some human creativity, the real answer to any design problem.

AVR: A Pebble Bed Success Story

I have discussed the criticisms of the AVR reactor in the Moormann report, and the unscrupulous use of this report by Steve Thomas to attack the South African pebble bed reactor program, which holds such promise for developing Africa. Now let's look at what a success story the AVR and its sister pebble bed reactor, the THTR, really were.

In 1959, the agreement on the construction of a pebble-bed reactor was signed by BBC/Krupp and Arbeitsgemeinschaft Versuchsreaktor GmbH (AVR Experimental Reactor Group). Construction of the AVR, a 15-megawatt-electric demonstration reactor was the first high-temperature reactor to use a pebble bed core, as developed by scientist Rudolf Schulten, the director of the Jülich Nuclear Research Center.

General Atomics

The 300-megawatt THTR was unique, having a pressure vessel made of prestressed concrete, instead of the usual steel.

Construction began in 1961, and the AVR went critical in 1966. A year later, the AVR was supplying electricity to the grid. The AVR was originally designed to breed uranium-233 from thorium-232. Thorium-232 is about 400 times as abundant in the Earth's crust as the fissionable uranium-235, and an effective thorium breeder reactor would be considered valuable technology. However, the fuel design of the AVR contained the fuel so well that the transmuted fuels were uneconomical to extract at the time. As a result, the AVR became a test-bed for different formulations of reactor fuel with different coatings. During the 21 years that the AVR operated successfully, 18 different types of pebble fuel were tested. Until the AVR was shut down in 1988, new types of fuel pebbles were loaded into the core.

The AVR tested the pebble bed's main safety features. In one test, during the 1980s, the AVR reactor was brought to full power and the coolant flow was stopped, to demonstrate a loss-of-coolant accident. It was found that one of the main design safety features, the negative coefficient of reactivity (as the reactor fuel gets hotter, it becomes less reactive), responded beautifully as planned. With all coolant lost, the reactor temperature increased but the reactor shut itself down.

After the operating success of the AVR, another, larger HTR was was constructed in 1983, the Thorium High-Temperature Reactor, THTR-300. Like the AVR, the THTR had a pebble bed design core. The core contained about 670,000 spherical fuel balls, each 6 centimeters in diameter. This reactor was unique, in that the pressure vessel that housed the pebble bed was formed of pre-stressed concrete—the first time this material had been used instead of a steel pressure vessel.

The THTR operated successfully for five years, with only a minor water ingress accident, where water from a burst tube in the steam generator leaked into the reactor core. Nevertheless, both the AVR and the THTR were shut down in 1988, because of the anti-nuclear hysteria that surrounded the aftermath of the Chernobyl reactor accident in April of 1986.

The Beauty of Modular HTRs

High-temperature reactors are the keystone to development because they are modular, and can be built in remote areas like rural areas in India or small city areas in Africa. These reactors can provide electricity and at the same time, provide high-temperature process heat for water desalination where needed, or for producing hydrogen. The fact that these reactors are modular, means that they could be built on site of industrial companies, for example, petrochemical plants, to provide high-temperature process heat to make better plastics. This would be a great benefit to industry, which right now burns large amounts of natural gas just to produce the needed process heat.

All of the possible uses of the pebble bed or the General Atomics prismatic block HTRs are limited only by man's imagination!

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