The Pebble Bed Modular Reactor

The Pebble Bed Modular Reactor (PBMR), like most new reactor ideas, is a reincarnation of an old reactor idea. In this case the old idea is the “high temperature gas reactor” or HTGR, that then was proposed in a modular version, known as the MHTGR. The PBMR is a variant of the HTGR. (The IEER book, The Nuclear Power Deception (New York: Apex Press, 1999), contains an analysis of the MHTGR, including safety issues.)

One permutation of the letters PBMR is MPBR. This is how it is called by the joint research team composed of the Massachusetts Institute of Technology (MIT) and the Department of Energy’s Idaho National Engineering and Environmental Laboratory (INEEL). DOE has designated the latter as the lead lab for the government’s efforts in the field of commercial reactor research and development.

HTGRs are cooled by helium gas, which is inert. They use graphite as a moderator (instead of water, which is the moderator in most existing nuclear reactors). Graphite is also used in Chernobyl-type (RBMK [1]) reactors, which are water-cooled, and in British Advanced Gas Reactors, which are cooled by carbon dioxide. Some graphite-moderated reactors use slightly enriched uranium fuel; others use natural uranium. Descriptions of various reactor types can be found on IEER’s web site.

One large-scale, 330-megawatt-electrical, HTGR has been built in the United States – the Fort St. Vrain reactor in Colorado. It was a commercial failure and was closed in 1989. It routinely faced operating problems and had a forced outage rate of over 60 percent. Its lifetime capacity factor was only 14.5 percent. Baseload power plants, like nuclear power plants, are normally designed to have capacity factors of 75 percent or more. Cost calculations by PBMR advocates use a 90 percent capacity factor.

The designers of PBMRs claim to have learned lessons from experience. In the PBMR, the hot helium drives a turbine directly, reducing the chances for water-graphite contact. There is a secondary water loop, however. The water is used to cool the helium gas before it is sent back to the reactor. The water usage would be lower than in light water reactors, since the projected efficiency of the PBMR is higher. For the South African promotional site on the PBMR, which contains diagrams, see http://www.pbmr.co.za/.

PBMRs would have uranium dioxide fuel coated with silicon carbide and pyrocarbon. The fuel would be fabricated into tiny particles, like grains of fine sand, called microspheres. In a PBMR, a larger size container, 60 millimeters (a little less than two-and-a-half inches) in diameter, is filled with these fuel grains. These fuel balls continuously flow through the reactor, and are mixed with balls made of graphite, which is used as a moderator. There would be 360,000 fuel balls, or pebbles, per reactor core, each containing 11,000 microspheres of fuel, for a total of about 4 billion microspheres per 110 megawatt reactor. There would be neutron absorbing balls and six control rods, according to the proposed design. About one-third of the pebbles would be discharged from the reactor every year. These figures apply to a design being considered by MIT and INEEL.

British Nuclear Fuels, owned by the British government, along with other corporate partners, as well as the national South African utility, ESKOM, are in the process of designing a 110 megawatt-electrical PBMR to be built in South Africa. It would be a demonstration plant the consortium hopes will become the basis of a large export industry. Such a plant would have a power output equal to about one-tenth that of a large, light water reactor that is now common. Hence the term "modular."

The PBMR seems the latest nuclear industry attempt to sell new, improved, "inherently safe" reactors. This is an inherently misleading term. No commercial PBMR has actually been built and operated. A small German pilot reactor operated for 21 years and operated at 70 per capacity factor, according to the promoters of the PBMR (http://www.pbmr.co.za/).

The experience with HTGRs is decidedly mixed. The one large HTGR in the United States, the Fort St. Vrain reactor, had quite a lot of problems and was prematurely shut. PBMRs were proposed in the 1990s as possible reactors to use for waste transmutation. (See Science for Democratic Action vol. 8 no. 3, May 2000, for a description of IEER's transmutation study.)

An analysis of the safety issues related to such use of PBMRs is provided in a 1996 study on transmutation by the National Research Council of the National Academy of Sciences. That safety analysis does not directly apply since the operating conditions and fuels would be different than the proposed PBMR. However, it is noteworthy that the study concluded "At this stage of its conceptual development, there is little information about the safety features of the PBR [Pebble Bed Reactor], its dominant risk factors, or its environmental impact." The study further stated that "It is not clear how the core [of the PBR] would react to any event that may interrupt the flow of helium coolant." [2]

The proportion of components designated as "safety-related" in the proposed PBMR, and therefore subject to more stringent inspections, would be just about 15 to 20 percent, compared to between 40 and 50 percent for light water reactors. The smaller number of inspections may make the plant cheaper to operate, but it may also render it more vulnerable to accidents. The Three-Mile Island accident started with a "non-safety" component, a valve in the condensate system inadvertently closed. It was the thirteenth time in a year that a non-safety component in that system had caused a reactor trip. Since it was a "non-safety" component, it was not inspected. Had it been a safety component, it would have been.

While the design of PBMRs would avoid fuel meltdown type accidents, a loss of the coolant could still produce serious radiological consequences. PBMRs will contain graphite, which could catch fire if air enters the core after a loss of the helium coolant. Further, a loss of coolant accident that involved a breach in the separation between the helium and water circuits poses a risk of steam-graphite reactions, which generate carbon monoxide and hydrogen, which would give rise to a fire hazard.

In sum, PBMRs have their own safety vulnerabilities, specific to their design, and should not be called "inherently safe." Note that the PBMR proponents still want the government to insure their reactors under the Price Anderson Act. Might this indicate a lack of confidence in its inherent safety?

If the reactor is built without a secondary containment, as has been proposed, this could result in a large release of radioactivity. If it is any consolation, the amount of radioactivity in the reactor core per unit of power produced is lower than with other reactor designs, because the fuel pebbles flow continually out of the reactor and are put into storage while new fuel pebbles are fed at the top. This reduces the inventory of short-lived radionuclides, such as xenon-133 and iodine-131, that might be released in the event of a severe accident. It is very questionable that a modular reactor of 110 megawatts could be made economical if a secondary containment were required, as it should be. It is important to remember that the secondary containment was the single feature that prevented the Three-Mile Island accident from releasing vast amounts of radioactivity that would have made it more comparable in scale to Chernobyl.

MHTGRs are more vulnerable to terrorist attack than light water reactors (see Nuclear Power Deception). It is unclear if this vulnerability of MHTGRs would also apply to the PBMR since a detailed design is not available.

PBMRs would use fuel enriched to a considerably higher level than present-day power reactors. Figures in the range of 8 to 20 percent have been proposed, with the former being the currently favored number. While such 8 percent enriched uranium cannot be used for making nuclear weapons, it would take far less work to make weapons grade uranium from PBMR fuel than from light-water reactor fuel (under 5 percent enrichment).

About 20,000 PBMRs would be needed over the next four decades or so to make a contribution to global electricity supply that would have a significant impact on carbon dioxide emissions. Allowing a decade for reactor development (a very short time, considering none have been built), that would be almost two reactors per day being brought on line for thirty years after that. Quality control for so many reactors and their regulation would be essentially impossible. Further, were a design problem found in the PBMR a decade or two after the hectic construction phase began, it would become economically prohibitive to fix it.

Fuel production for 20,000 units would have to be about 25 trillion microspheres per year. How the quality control would be implemented for such a huge supply of a relatively novel fuel would be a crucial issue for the PBMR. In this context, it is worth noting that one of the corporations leading the charge for the PBMR is BNFL, the British government-owned company that has admitted that some of the plutonium oxide-uranium-oxide (MOX) fuel that it sent to Japan had fabricated quality control data.

Finally, there are a number of questions associated with PBMR waste. While PBMRs would reduce the amount of waste volume per unit of power production, there would still be an enormous of amount of radioactive waste that would result, posing the familiar problem of what to do with long-lived radioactive waste. Further, the interaction of the carbon and silicon carbide-coated fuel of the PBMR with the repository environment has not been studied in any detail.

Despite the vast number of the problems relating to the waste being generated by the current crop of power reactors, the Bush administration and the nuclear industry seem set to encourage new reactor orders without a significant social debate about where the waste would be put. Yucca Mountain, even if it were to be licensed, is prohibited by law from accepting more than 70,000 metric tons of spent fuel and is unlikely to be able to accommodate vast new amounts of nuclear waste even if it were to be licensed.

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Arjun Makhijani is the president of the Institute for Energy and Environmental Research. This is an advance copy of an article that will appear in Science for Democratic Action vol. 9 no. 4 *(August 2001)*

Notes:

1. Russian acronym for Reactor Bolshoi Moschnosti Kanalynyi "Channelized Large Power Reactor." ? Return
2. Commission on Geosciences, Environment, and Resources of the National Research Council of the National Academy of Sciences, Nuclear Wastes: Technologies for Separations and Transmutation, Committee on Separations Technology and Transmutation Systems, (Washington, DC: National Academy Press, 1996), p. 292 ? Return