Safety issues with the South African Pebble Bed Modular Reactor: When were the issues apparent? A briefing paper

by

Steve Thomas

Professor of Energy Policy, PSIRU, University of Greenwich, London

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PSIRU, Business School, University of Greenwich, Park Row, London SE10 9LS, U.K.
Website: www.psiru.org *Email:* psiru@psiru.org *Tel*: +44-(0)208-331-9933 *Fax*: +44 (0)208-331-8665
Researchers: Prof. Stephen Thomas, David Hall (Director), Jane Lethbridge, Emanuele Lobina, Vladimir Popov, Violeta Corral

1. Safety issues with the South African Pebble Bed Modular Reactor: When were the issues apparent?

In July 2008, the German Jülich nuclear research centre published a report entitled 'A safety re-evaluation of the AVR pebble bed reactor operation and its consequences for future HTR concepts.' It concluded: 'pebble bed HTRs require additional safety related R&D effort and updating of safety analyses before construction.'

The fundamental reason for these conclusions is that it has, with this study, become clear that the temperatures that were experienced in the German prototype plant, the AVR, were more than 200 degrees C above those anticipated in the design. This led to massive contamination of the plant as well as major safety issues. These high temperatures have been known about since before 1990 and cannot be explained, as had been previously assumed, by inadequate fuel quality only.

Given that this research was produced by the research institute that pioneered high temperature reactor work in Germany (the Pebble Bed Modular Reactor is a type of high temperature reactor) and that the AVR was designed by the Jülich Centre, these findings cannot be ignored. If they are valid, it is inconceivable that the PBMR programme could proceed in anything like its present form and the earliest date for commercial availability of this technology is now far in the future.

The PBMR programme has been promoted and funded primarily through South African government-owned bodies, such as the nationally-owned electric utility, Eskom, by the company set up to develop the technology, PBMR Co, the government's Industrial Development Corporation (IDC) and by government departments directly. The question therefore arises, who knew what and when about this potential problem?

2. Historical background and costs incurred

High temperature gas-cooled reactors have been under development in Germany, primarily through the German government's Jülich research centre, since the 1950s. Jülich was set up in 1956 by the North-Rhine Westphalia State and in 1967 became a limited company. The shareholders are the German state (90 per cent) and the North Rhine Westphalia government (10 per cent). A prototype plant at Jülich, AVR, which produced 15MW of electrical power, was ordered in 1959 and operated from 1967-88. This was followed up by a demonstration plant, THTR-300 (300MW), which operated went critical in 1983 but last generated power in 1988 and was formally closed in 1989. While the AVR was generally portrayed as highly successful, the operating record of the THTR-300 was poor. It was closed after only a few years of highly erratic operation because of difficulties obtaining funding for its continued operation. However, public opposition and technical issues would have made its continued operation problematic. The technical problems were such that later design concepts were based on the AVR rather than THTR-300. Subsequently, the THTR-300 designer, ABB, joined forces with Siemens, which had also designed a similar size plant producing a new design. The joint venture company, HTR, promoted this design for a couple of years before giving up active promotion of it although continuing to sell technology licenses, including to South Africa and China.

The ownership of HTR has changed as its original owners have been subject to merger and takeover activity. ABB was bought in the late-1990s by the UK government owned nuclear technology company, BNFL, which merged it with the Westinghouse nuclear business which it bought at about the same time. In 2006, it spun off the Westinghouse division and sold it to the Japanese company Toshiba. Siemens' nuclear division was merged with that of the French company, Framatome to form Areva NP, owned 66 per cent by the French parent company, Areva and Siemens (34 per cent).

The design was taken up in three main countries, China, Russia and South Africa, in the latter case from 1993 onwards in the publicly owned electric utility, Eskom. HTR co-operated with Eskom who produced a design which, unlike its predecessors, was expected to generate electricity using a gas turbine driven by the helium coolant gas rather than via a heat exchanger and a conventional steam circuit. In 1998, these efforts were made public and it was then forecast by Eskom that following completion and operation of a demonstration plant, commercial orders would be possible from 2004 onwards. In 1999, Eskom took a license from HTR for pebble bed technology. In 2000, a new company, PBMR Co, was set up to complete a feasibility phase. This company was 100 per cent owned by Eskom, but other investors were brought in to fund this phase. This funding would allow them to take up shares in a successor company to PBMR Co that would complete a demonstration phase in which a demonstration plant would be built and operated, and commercial sales would be placed.

The original design has been uprated in its power output from 110MW when the project was made public in 1998 to 165MW, although still retaining essentially the same physical dimensions as the original 110MW design to improve the economics through scale economies.

The investors in this company varied but the main ones were: British Nuclear Fuels (BNFL), the UK government owned nuclear technology company that promised 22.5 per cent of the funding for the feasibility phase in 2000; Exelon, a US electric utility that took 12.5 per cent in 2000; and the South African government's Industrial Development Corporation (IDC), which took 25 per cent, also in 2000. 10 per cent was reserved for an Economic Empowerment Entity with Eskom expected to take the remaining 30 per cent. Things turned out very differently. Exelon withdrew in April 2002 and while it did pay some of the money promised, it is not clear whether it fulfilled the full 12.5 per cent quota. BNFL ran into financial problems in 2002 and stopped funding in 2003 paying only 15 per cent of the cost of the feasibility phase. IDC, unreported at the time, reduced its stake to 13 per cent in 2002. The Economic Empowerment Entity stake was never taken up so Eskom's contribution was 60 per cent, rather than the 30 per cent planned. South African public money, which should have funded 55 per cent of this phase actually funded about 75 per cent.

There was no official announcement of when the feasibility phase actually finished but it appears to have been in March 2004, by which time, PBMR Co stated that R1.4bn had been spent, of which it seems about R1bn had come from South African public money. By July 2008, the successor company had still not been set up and no partners had agreed to fund the demonstration phase. It appears that the running costs of PBMR Co from March 2004 onwards, still 100 per cent owned by Eskom, were met by South African public money, mostly from direct government grants. There is no definitive information on what the running costs for PBMR Co are. Terblanche[1], chair of PBMR Co, indicated in 2004 that monthly costs were 'a lot more than' R50m. In February 2005, when the government's budget was announced, the government support for PBMR in that year was R600m. So as a minimum, if we take R50m as the monthly running cost of PBMR Co, a further R2.5bn has probably been spent from March 2004 to end of June 2008, making a total of about R4bn, of which R3.5bn is South African public money.

A number of contracts have also been placed. For example, by December 2007, four contracts had been signed with the German fuel company, Nukem and contracts had been signed with another German company, SGL Carbon for supply of graphite. The value of these contracts has not been published. The largest contract is probably with Spain's Equipos Nucleares S.A. which has a contract worth a total of R312m for design and delivery of components for the plant's main power system pressure boundary, including the pressure vessel. No definitive list of the contracts that have been placed and their value exists.

An international panel was set up in 2002 to review the PBMR but its findings were never made public. It was told in early 2002 that the final design would be sent to the South African National Nuclear Regulator within about 6 months. By May 2008, PBMR Co was saying that the design was still 6 months away from completion. Numerous target dates for setting up the new PBMR Co with

[1] Financial Mail, March 26, 2004, p 14.

its new investors have come and gone. Most recently, in April 2008, the Public Enterprises Minister, Alec Erwin, claimed the new company would be launched in May 2008, but this date again passed with no action. There have also been constant reports that new investors were eager to sign up to the demonstration phase, but these reports have also proved optimistic and no investors in the next phase have been confirmed beyond the South African government.

As the delays with the PBMR mount and the power shortages in South Africa worsen, Eskom and the government seem now to be relying on orders for what they term 'conventional' nuclear power plants. These, the Westinghouse AP-1000 and the Areva EPR are plants similar in design to the plants that already exist at Koeberg in South Africa. No plants of these two designs have yet been completed. Eskom expects to place an order for 3600MW of capacity in 2008 with an option for a further 20000MW. The two companies bidding to supply these plants, Areva NP and Westinghouse, are the technology licensors for PBMR technology.

3. What are the problems and when were they known about?

The AVR has been portrayed to the South African public as an unqualified success. A German nuclear scientist, Peter Pohl, told the Carte Blanche programme: 'what was achieved is unique, in temperature, in burn up, in reliability - it's just fantastic.'[2] The Jülich report presents a different view. In 1978, there was a water ingress incident when water from the cooling circuits entered the reactor and this seems to have caused contamination of the soil at the site with highly radiotoxic Strontium-90. The result is that the reactor vessel has to be filled with concrete to immobilise the radioactive dust (see below) and to stabilize the vessel, and the 2000 tonne structure has had to be airlifted from the site to a remote store pending its decommissioning so the soil contamination at the site could be dealt with. Such a water ingress should not occur in the South African PBMR design because it uses a gas turbine rather than a steam turbine but the incident still raises very serious and potentially costly issues about the containment of the reactor.

The AVR was only operated for about 4 reactor years at high gas temperatures of greater than 900C. These are the temperatures that would be required for very high temperature reactors – the sort of plant that could be used, for example, to extract oil from tar sands or liquefy coal. PBMR Co has often alluded to the potential for the PBMR to operate at these higher temperatures to win this market and it has expressed interest in gaining US government money to develop such reactors.

The President of the South African Institute of Nuclear Engineers, John Walmesley wrote in April 2008:

> 'The reactor has the potential to operate at temperatures around 950°C. In other words, the helium gas that carries the heat out of the reactor exits the reactor pressure vessel at that temperature. This red-hot gas does not have to be used to make electricity. At that temperature it can be used to split water to make hydrogen, believed by many to be the fuel of the future. The Americans propose to build the Idaho "new generation nuclear plant" (NGNP), for which the PBMR is the front-runner, to show it can be done. To date, $1.1 billion has been allocated. The hot helium can also be used to heat coal hot enough to convert it to oil, a possible application of great interest to Sasol.'

In 1988, after a decision to close the plant had already been taken, it emerged that fuel temperatures in the AVR could have exceeded 1400C, more than 200 degrees higher than the expected maximum temperature. The regulatory permission to operate at gas temperatures of 950°C was withdrawn and the plant shut down permanently soon after. No mention is made of this withdrawal of the operation permit for 950°C in the 1991 final report on the AVR. This report states: [3]

> 'At an average hot gas temperature of 950°C the highest fuel temperatures were around 1300°C and the highest surface temperatures were only slightly lower. However these values do not represent a serious load because of the full ceramic design of the fuel element.'

[2] http://www.mnet.co.za/Mnet/Shows/carteblanche/story.asp?Id=3516

[3] AVR- Experimental High-Temperature Reactor. 21 Years of Successful Operation for a Future Energy Technology. Association of German Engineers (VDI) - The Society for Energy Technologies (Publ.) 1990.

In contrast the AVR is still portrayed as a prototypic facility for VHTRs (Very High Temperature Reactors). Indeed the final report on AVR was entitled: 'AVR-Experimental HTR: 21 years of successful operation for a future energy technology.'

The AVR reactor circuits are massively contaminated. The Jülich report states:

> 'the end of life contamination reached several percent of a single core inventory, which is some orders of magnitude more than precalculated and far more than in large LWRs. A major fraction of this contamination is bound on graphitic dust and thus partly mobile in depressurization accidents, which has to be considered in safety analyses of future reactors.'

In short, in any normal reactor, almost all the radioactivity at the plant is contained in the fuel with only a minute percentage due to contamination of the reactor itself. For AVR, it is several percent of the radioactive inventory. The consequences for decommissioning of AVR have not been the subject of much public debate in Germany. Some feel for the scale can be gained by a 2002 report which said that the expected decommissioning cost of AVR was $490m compared to the estimates of $20m that were given by the plant's owners in the 1990s[4]. It seems highly likely that the estimate of $490m has grown substantially since 2002.

The Jülich report shows that the assumption that the high temperatures were solely the result of poor quality fuel was incorrect and that other factors, as yet unknown, were involved. It was previously assumed by PBMR's proponents that the issues raised by the high observed fuel temperature were not relevant to the South African PBMR because the fuel quality problems would not arise. According to PBMR Co, the outlet temperature would be 900C and the maximum fuel operating temperature should not exceed 1130C. If the large temperature variations observed in the AVR are a guide, the maximum fuel operating temperature is likely to be exceeded and the safety case does not stand. For example, it seems likely a gas-tight containment would be needed. The need for a containment (this keeps radioactivity within the reactor building in the event of an accident) has been a subject for discussion for some time and if it was needed, the additional cost for the PBMR would be prohibitive.

The Jülich report suggests that a gas-tight containment should be included in any commercial pebble bed plants and that a large programme of R&D be conducted as well as a re-evaluation of the safety case.

While the full extent of the problems is only now becoming clear, the high temperatures experienced at AVR were known about 20 years ago and it would seem fair to suggest that the German authorities should not have made the unsupported assumption that poor quality fuel was solely to blame, nor should they effectively have swept the issue under the carpet by not including any mention of the severe consequences of high temperatures in the final report on AVR.

In terms of the South African involvement, the issue should have become clear by 2002 if not before. In 2000, the PBMR Co was joined by the US utility PECO (later it merged with another utility to become Exelon). This was a major step forward for PBMR Co as PECO promised to place ten orders for the plant (the only firm orders for the PBMR that have ever existed) and, even more important, agreed to pilot it through the safety regulatory process in the USA. If the PBMR was to be sold on international markets, regulatory approval by an authority with the prestige and credibility of the US Nuclear Regulatory Commission (NRC) was essential. The process started in 2001 and by the start of 2002, the NRC was asking significant questions on core temperatures.[5] In April 2002, Exelon withdrew from PBMR Co. The process of regulatory approval continued for some time and was officially closed in September 2002[6] but only after some very searching questions had been asked.

[4] Nucleonics Week 2002 'Decommissioning cost for German pebble bed reactor escalating' July 4, 2002.
[5] http://www.nrc.gov/reactors/new-licensing/design-cert/pre-app-review/2002.html
[6] http://www.nrc.gov/reactors/new-licensing/new-licensing-files/ml022530263.pdf

Exelon's stated reasons for withdrawal were rather vague and it is not clear how far the issues that NRC raised contributed to this decision. John Rowe, the CEO of Exelon was quoted as saying: 'the project was three years behind schedule and was "too speculative,"'[7]. He also said: "a detailed review that Corbin [McNeil, the joint CEO of Exelon] and I started late last summer yielded a recommendation from the people in charge of the project that ...[operation and testing was] three years further out than we had thought a year ago."

Eskom and PBMR Co would certainly have been aware of the NRC's questions. It subsequently emerged that in 2002, Eskom was discussing withdrawal from the project at Board level after it received a very luke-warm assessment of the PBMR project in a report it had commissioned from consultants PWC. But it was argued that withdrawal was not politically feasible. How far these discussions were also informed by the issues NRC were raising is not known.

The Legal Resources Centre, on behalf of Earthlife Africa picked up on these concerns in September 2002 in its submissions responding to Eskom's EIA application for authorisation to build a demonstration module PBMR and nuclear fuel manufacturing operation. This stated[8]:

> 'the EIR [Environmental Impact Report] understates: the temperature the PBMR could attain; the rate of radioisotope releases from the fuel spheres; and the risk of ignition of the core as a result of sudden ingress of air. The submission also argues that the EIR wrongly concludes that containment is not required by the 'defense-in-depth' principle.'

The South African National Nuclear Regulator (NNR) did not have a formal agreement to cooperate with NRC at that time, but there were informal connections and it would have been extraordinary if they had not followed the US process very carefully. As a newly founded regulatory body with no substantive experience of licensing a reactor, much less a first-of-a-kind design, they were in an extremely exposed position. Documents submitted by PBMR Co to the NRC were authored by Maurice Magugumela then an employee of PBMR Co, who, in 2005 became the CEO of the NNR.

4. Conclusions

Unless the results of the Jülich study can be dismissed as having no foundation, it is inconceivable that the PBMR project can proceed in its present form. The problems that occurred at AVR have been ignored despite mounting evidence, if only through the scale of decommissioning problems at AVR. The result is that somewhere in the region R4bn, of which more than R3.5bn is South African public money, has been spent developing a reactor which now seems to be decades away from commercial deployment. There seems strong *a priori* evidence that those involved in the project should have been aware of the issues at least from the point when NRC began to raise serious questions in 2002, if not earlier. A full and open public inquiry is required to determine who knew what and when, and why these danger signals were ignored.

[7] Energy daily, April 24, 2002.

[8] Legal Resources Centre (2002) 'Submissions on the Pebble Bed Modular Reactor and associated fuel manufacture: Draft environmental impact reports. Analysis of legal compliance' Legal Resources Centre, Cape Town, September 2002.