The Economic Impact of the Proposed Demonstration Plant for the Pebble Bed Modular Reactor Design

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1. Executive Summary

1.1 The Issues

This report examines the economic case put forward in the Final Environmental Impact Report (FEIR) submitted in respect of the application by Eskom to build a Demonstration Plant at the Koeberg site in the Western Cape, using the Pebble Bed Modular Reactor (PBMR) nuclear technology being developed in South Africa. The analysis of the economic impacts is required under the terms of the National Environmental Management Act.

In June 2003, the Director-General, Chippy Olver, of the Department of Environmental Affairs and Tourism (DEAT) approved (a positive 'Record of Decision' (ROD)) the Eskom's Environmental Impact Assessment for the building of a demonstration PBMR and an associated fuel manufacturing plant. Earthlife Africa (ELA) launched a High Court application in Cape Town, which sought to review and set aside this ROD.

On January 26 2005, ELA obtained a judgement in the High Court in the Cape Provincial Division which set aside the PBMR's authorisation. By August 2005, the process to authorise the demonstration PBMR had not been re-opened.

The report focuses especially on the life cycle costs of the Demonstration Plant and any commercial successor plants. In isolation, the Demonstration Plant will inevitably be a heavily loss-making project, but it is hoped by the promoters of the project that profits from an export-led programme of commercial units will more than pay for these losses. It is therefore necessary to analyse not only at the economics of the Demonstration Plant, but also the prospects for commercial sales to assess the economic case for the Demonstration Plant.

Section 2(3) of the National Environmental Management Act stipulates that the state should ensure that development must be socially, environmentally and economically sustainable[1]; while section 2(4)(i) requires that "the social, economic and environmental impacts of activities, including disadvantages and benefits must be considered, assessed and evaluated and decisions must be appropriate in the light of such consideration and assessment".

The main publicly available sources of information on the PBMR programme are:

- The Final Environment Impact Report ("FEIR") (PBMR, 2002b) prepared by the PBMR EIA Consortium for the Applicant, Eskom;
- The Detailed Feasibility Report or DFR (PBMR, 2002a) prepared by PBMR (Pty) Ltd; and
- The Register of Comments and Responses on Draft EIRs (Register of Comments, 2002) published in June 2002, which contains responses by the consultants to public comments to the Applicant, Eskom, on the draft Economic Impact Assessment "DEIR".

The main factors that must be considered in the economic analysis of the Demonstration Plant are:

- The partners in the PBMR venture, especially foreign companies;
- Safety licensing;

[1] principle 2(3)

- Construction cost and cost of other new facilities required;
- The cost of capital;
- The plant's maximum electrical output;
- Operating performance especially reliability;
- Operations & maintenance cost, including fuel supply and spent fuel disposal;
- Decommissioning cost; and
- Operating life.

Forecasts of the economic parameters are also required to assess the prospects for the commercial programme. In addition, a world market evaluation is required. The documentation provided in the FEIR provides almost none of the information required to assess the economic sustainability of the PBMR Demonstration Plant. To consider this, it is necessary to look at the life-cycle costs of the Demonstration Plant. However, given that by its nature, a demonstration plant will not be economically viable by itself, it is necessary to look at who will bear the uneconomic costs of the plant and also what the prospects of success for commercial PBMR units are.

1.2 Conclusions

1.2.1 The Demonstration Plant

Conclusion 1: Regardless of its success or otherwise, the Demonstration Plant will leave a substantial liability that will fall on South African public funds caused by the need to decommission the plant and the associated facilities, and to pay for the disposal of the spent fuel. The FEIR and the DFR do not quantify these liabilities, providing no information on spent fuel disposal and no usable information on expected decommissioning cost. However, experience in other countries suggests that decommissioning costs could be of the same order of magnitude as construction costs.

Conclusion 2: Since details of the project were made public in 1998, costs of the Demonstration Plant have escalated by a factor of more than seven. The project lead-time has slipped so that it is now apparently further away from commercial exploitation than it was in 1998 when commercial orders were forecast to take place from 2003. Now, seven years on, commercial orders are not forecast for about ten years. This shows that the developers failed to understand the scale and nature of their task. There is still considerable scope in the next phase for further cost escalation and delay due to changes to the design and construction problems. The developers' poor record to date gives little confidence in their ability to control costs and time schedules in the next, more expensive phase.

Conclusion 3: Forecasts of other economic parameters, such as operating performance, operating cost and decommissioning cost have not been updated since 1998 and appear implausibly optimistic. It is understandable that developers of a project have an optimistic view of the project's prospects – 'appraisal optimism'. However, investment decisions should be taken on the basis of sober, unbiased judgements of the most likely outcomes, not the views of the project's promoters.

Conclusion 4: PBMR (Pty) Ltd successfully diversified some of the risk away from the South African public for the feasibility phase with foreign partners, Exelon and BNFL Ltd, sharing the costs. However, the cost of this phase (about R2bn) was far more than forecast and the absolute amount paid for by the South African public was not reduced. PBMR (Pty) Ltd has spoken optimistically over the past three years about the prospects of recruiting new partners to replace Exelon and BNFL (if as seems likely it cannot participate), but nothing has come of these negotiations. Until there is solid evidence of new partners being bought in, it must be assumed that the cost of the demonstration phase will fall substantially on the South African public, through Eskom, IDC, or direct government subsidies.

1.2.2 The commercial programme

Conclusion 5. PBMR (Pty) Ltd's analysis of the world market for PBMRs is simplistic, taking no account of any of the commercial or political factors that would apply in key export markets. A particular concern is finance for export orders. This is an important issue for developing countries, which are likely to account for a significant proportion of the forecast orders. Such countries frequently have difficulty financing large investments. The World Bank and most other International Financial Institutions do not provide finance for nuclear investments. The South African PBMR could face strong competition from other types of high temperature reactor, notably a very similar Chinese design and models offered by Areva and the US company, General Atomics. Until a rigorous market analysis has been carried out and subjected to independent scrutiny, and arrangements for helping finance export orders made explicit, PBMR (Pty) Ltd's assumptions on the likely world market have no basis.

Conclusion 6. Pressure is mounting on Eskom to commit to buy large numbers (24) of commercial units even before the technology has been technically and economically proven at a cost in excess of R25bn. Eskom appears, rightly, to be holding to its position of only buying it if the PBMR is the cheapest option available, something that will not be known until the Demonstration plant is in service and has operated for some time. If Eskom is required to make such an advance commitment, it could be forced to purchase uneconomic plants, raising the price of power to consumers, and adversely affecting public welfare and the competitiveness of the South African economy.

Conclusion 7. The future of Eskom is uncertain. The South African government has been considering reforms to Eskom for a number of years, including its privatisation and its break-up into competing units. There can be no guarantee that in 2013 or later, when the first commercial orders for a PBMR might be placed that Eskom will exist in any recognisable form, much less one that can be obliged to order a particular type of power plant, especially if it does not represent the best commercial option.

1.2.3 Overall conclusions

Conclusion 8: The PBMR project is a highly risky venture. The feasibility phase has cost more than R2bn, about two thirds of which has been paid by South African public money. Despite this expenditure, there is still ample scope for the project to fail. The next phase will require a much higher level of expenditure, at least R14.5bn, with more than half of this again coming from the South African public. If the project fails, there will be significant consequences for the South African public either through higher electricity prices (if Eskom is forced to bear much of the risk) or through taxation if the government has to write-off the costs.

Conclusion 9: The National Environmental Management Act (NEMA) requires developers to demonstrate that their projects are economically sustainable. The FEIR does not provide the data necessary to make such a judgement. This information strongly suggests there is a high risk that the project will not be economically sustainable. On the available evidence, the project does not meet the requirements of the NEMA and the applicants, Eskom, should not be given approval.

Conclusion 10: The current high fossil fuel prices and the measures to reduce greenhouse gas emissions seem to give a new impetus to generation technologies that do not use fossil fuels. However, it should be remembered that previous oil price spikes (1974 and 1980) were short-lived and resulted in little nuclear investment apart from in France. Investors are unlikely to make multi-million dollar investments in new nuclear power plants on the basis of a short-term oil price spike which could have disappeared long before a nuclear plant could be brought on-line. On greenhouse gas emissions, nuclear power faces competition from renewable technologies and energy efficiency measures, options that generally do not encounter the public acceptability problems that nuclear power suffers from.

2. Introduction

This report examines the economic case for building a Demonstration Plant at the Koeberg site in the Western Cape, using the Pebble Bed Modular Reactor (PBMR) nuclear technology being developed in South Africa. An analysis of economic impacts is required under the terms of the National Environmental Management Act. The report focuses especially on the life cycle costs of the Demonstration Plant and any commercial successor plants. In isolation, the Demonstration Plant will inevitably be a heavily loss-making project, but it is hoped by the promoters of the project that profits from an export-led programme of commercial units will more than pay for these losses. It is therefore necessary to analyse not only at the economics of the Demonstration Plant, but also the prospects for commercial sales to assess the economic case for the Demonstration Plant.

This report covers most of the main costs involved in the operation of a nuclear power plant. This report does not cover the costs of radioactive waste disposal, disposal of spent nuclear fuel, nor does it consider the cost of a catastrophic accident, although these factors are clearly important.

It also does not cover the cost of competing fossil fuel technologies. However, it should be noted that while the current high fossil fuel prices and the measures to reduce greenhouse gas emissions seem to give a new impetus to generation technologies that do not use fossil fuels, this may not lead to a revival in nuclear ordering. It should be remembered that previous oil price spikes (1974 and 1980) were short-lived and resulted in little nuclear expansion apart from in France. Investors are unlikely to make multi-million dollar investments in new nuclear power plants on the basis of a short-term oil price spike which could have disappeared long before a nuclear plant could be brought on-line. On greenhouse gas emissions, nuclear power faces competition from renewable technologies and energy efficiency measures, options that generally do not encounter the public acceptability problems that nuclear power suffers from.

3. *The legal context*

The analysis of the economic impacts is required under the terms of the National Environmental Management Act. Section 2(3) of the Act stipulates that the state should ensure that development must be socially, environmentally and economically sustainable[2]; while section 2(4)(i) requires that "the social, economic and environmental impacts of activities, including disadvantages and benefits must be considered, assessed and evaluated and decisions must be appropriate in the light of such consideration and assessment". Such decisions must moreover be taken in an open and transparent manner and access to information must be provided in accordance with the law[3]. The assessment of environmental impacts in terms of NEMA must include the assessment of potential impact on the socio economic conditions and the assessment of the significance of that potential impact[4].

Paragraph 7.4.4 of the Scoping Report for the proposed PBMR set out the issues and concerns to be studied for the purposes of the EIA under the heading 'Economic aspects' as follows:

- The economic potential of a local based nuclear industry for local applicatory (sic) and export, should the plant prove its techno economic viability;
- Impact on eco-tourism in the region around Koeberg, i.e. 50km radius;
- Impact on supply side management based on the assumption that the plant is viable.

The issue of life cycle costing was added by the DEAT after receipt of the plan of study for scoping.[5]

The main documents backing the case for the Demonstration Plant are the Detailed Feasibility Report or DFR (PBMR, 2002a) and the Final Environment Impact Report or FEIR (PBMR, 2002b).

3.1 Economic sustainability

The National Environmental Management Act provides no guidance on what constitutes 'economic sustainability'. For a commercial project, that is, one that does not require (public) subsidies, economic sustainability would be relatively easy to define. It would require that the facility being built would have a high probability of being profitable. However, for a demonstration plant, the issue is more difficult to define. Clearly, the PBMR Demonstration Plant will not be an economic source of electricity on a full-cost basis, that is, including the cost of construction. It is therefore necessary to examine who will pay for the uneconomic cost of construction of the plant. It may not be an economic source of power even on a marginal cost basis, that is, revenues from the sales of the electricity it produces may not even cover the running cost of the plant. It is therefore necessary to examine who will be liable for the additional uneconomic operating costs.

However, the Demonstration Plant can only be properly evaluated in the context of the commercial programme of reactor sales that it is hoped will follow from the Demonstration Plant. This is clearly acknowledged in the conclusions of the DFR (PBMR (Pty) Ltd, 2002a, p 62), which state:

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[2] principle 2(3)
[3] Principle 2(4)(k)
[4] NEMA section 24(7)(b)
[5] DEAT Director-General's letter to the EIA consortium dated 2/5/01.

> In all scenarios, the PBMR is predicted to have a non-negligible effect on the South African economy. The macro-economic impact of building the demonstration plant only is small. The key benefit to the economy will come from the commercialization and sale of the PBMR on the international market. In these more optimistic scenarios, this impact is extreme, adding thousands of jobs a year and billions of South African rands to the GDP. Moreover, a larger portion of this money is anticipated to flow to the lower income groups than the average for the manufacturing sector. The results of this study indicate that the PBMR programme can add sufficient value to South Africa to offset the risks associated with building this first-of-a-kind nuclear reactor on South African soil.

Despite this, in the Register of Comments and Responses on DEIRs, the Applicant's consultants continually state (in 15 responses): 'the present EIA is limited to a single demonstration module PBMR' in response to questions about the overall programme.

This report therefore examines both the economic impact of the full life-cycle costs of the Demonstration Plant and also the likelihood that the Demonstration Plant would lead to a successful programme of sales of commercial PBMR units.

To evaluate the life-cycle costs of the Demonstration Plant, it is necessary to forecast:

- Construction cost and cost of other new facilities required;
- The cost of capital;
- The plant's maximum electrical output;
- Operating performance especially reliability;
- Operations & maintenance cost, including fuel supply and spent fuel disposal;
- Decommissioning cost; and
- Operating life.

The FEIR and the DFR do not provide clear forecasts of any of these parameters.

For the commercial programme, it is necessary to evaluate the competitiveness of the PBMR against other electricity generation technologies. This would require forecasts of all the above parameters. A detailed and convincing market analysis is also required, especially for a controversial technology like nuclear power, where it may not be sufficient to provide an economically competitive product if it is not politically acceptable. Again, no serious analysis of potential markets is provided.

3.2 Provision of information

The National Environmental Management Act states that 'access to information must be provided in accordance with the law'. In its Demonstration Feasibility Report, PBMR (Pty) Ltd (PBMR (Pty) Ltd, 2002a, pp 48-49) pays lip service to this requirement. It states:

> Since nuclear has traditionally been associated with a cloud of secrecy, preconceived notions and inaccurate reporting, the overriding philosophy in PBMRCo's Public Relations philosophy has been one of open and honest communication.
> This approach has been to:
>
> - share as much non-proprietary information as possible with all stakeholders;
> - provide proactive awareness using available media;
> - within reasonable limits, react swiftly and professionally to enquiries from the media and other interested and affected parties;
> - follow a general approach of collaboration rather than confrontation;
> - demonstrate a readiness to listen to, take note of and act upon the legitimate concerns of interested and affected parties;
> - communicate the benefits of the project and deal constructively with any perceived negative issues; and

- confirm Eskom's and PBMR's commitment to a transparent EIA in which all interested and affected parties are encouraged to participate.

The programme is ongoing and will continue beyond the demonstration phase of the PBMR.

The DFR, the FEIR and the more general flow of information on the programme to the South African public show the hollowness of this claim. Almost none of the economic information needed to evaluate the Demonstration Plant or the PBMR programme in general has been provided. The most recent set of data was written (for a British audience) five years ago (Nicholls, 2000). Most of the data used in this report has been gleaned from international sources, mainly Nucleonics Week, which is an authoritative trade journal, but which has a negligible circulation in South Africa. There is little evidence that PBMR (Pty) Ltd has provided: 'proactive awareness using available media', particularly for the South African public. This is especially reprehensible given that PBMR (Pty) Ltd and Eskom expect the South African public to be the major financial underwriter for the project.

3.3 Earthlife Africa's legal challenge

In June 2003, the Director-General, Chippy Olver, of the Department of Environmental Affairs and Tourism (DEAT) approved (gave a positive 'Record of Decision' (ROD)) Eskom's Environmental Impact Assessment for the building of a demonstration PBMR and an associated fuel manufacturing plant. Earthlife Africa (ELA) launched a High Court application in Cape Town, which sought to review and set aside this ROD.

On January 26 2005, ELA obtained a judgement in the High Court in the Cape Provincial Division which set aside the PBMR's authorisation. The basis of the judgement was that the ROD granting the authorisation was fatally flawed in that ELA had not been given an opportunity to make submissions to the DEAT on the FEIR even though it differed materially from the earlier report on which it was given a chance to comment. The Director-General made his decision without having heard ELA and without even being aware of the nature and substance of ELA's submission. The judge ordered that ELA be afforded an opportunity to address further written submissions on the FEIR. As of August 2005, the process to authorise the demonstration PBMR had not been re-opened.

4. The PBMR project

The Pebble Bed Modular Reactor (PBMR) is a new design of nuclear power plant developed from a German model built only as a demonstration plant in Germany, THTR 300, which was in service from 1983-89.

The main publicly available sources of information on the PBMR programme are the Detailed Feasibility Report or DFR (PBMR, 2002a) and the Final Environment Impact Report or FEIR (PBMR, 2002b). Also important is the Register of Comments and Responses on Draft EIRs (Register of Comments, 2002) published in June 2002, which contains responses to public comments on the draft Economic Impact Assessment. Note that the FEIR was substantially drafted before the withdrawal of Exelon. It contains a short section on the withdrawal of one of the partners in the project, the US utility, Exelon, but its sales projections are still based on Exelon buying the first 10 commercial units from 2006 onwards (PBMR, 2002b, p 194) even though it was by then clear that Exelon's commitment had lapsed with its withdrawal from the project. The most comprehensive independent review of the economic prospects for the PBMR programme was published by Auf der Heyde & Thomas (Auf der Heyde & Thomas, 2002). An earlier response by the Legal Resources Centre drew partly on this paper and some, mostly inadequate answers were provided by in a Register of Comments (Register of Comments, 2002).

4.1 The technology

The South African PBMR differs markedly from the designs of nuclear power plant that are dominant worldwide, the Pressurised Water Reactor (PWR, the type operating at the Koeberg site in the Western Cape, where Eskom expects to build the Demonstration Plant) and the Boiling Water Reactor (BWR) in five important respects:

- Coolant. The energy from a PWR or BWR is transferred from the nuclear core to the turbine (the equipment that transforms the heat energy into electricity) using water. The turbine, similar to that used in a conventional coal plant, is driven by steam. In a PBMR, the coolant is helium gas, which drives a gas turbine (similar to a jet aircraft engine);[6]
- Moderator. The moderator, the medium that ensures the energy of the nuclear reaction is efficiently exploited, is water in PWRs and BWRs, whereas it is solid graphite (a form of carbon) in a PBMR;
- Fuelling. In a PWR or BWR, the nuclear fuel is enriched (the proportion of the 'fissile' uranium isotope) from about 0.7 per cent in naturally occurring uranium to about 3.5 per cent. The fuel is in the form of uranium oxide fuel rods and the reactor must be shut down about once a year for about a third of the old fuel rods to be replaced with fresh fuel. In a PBMR, the fuel is expected to be enriched to about 8 per cent and is in the form of 'pebbles' the size of a snooker ball. These are continuously fed into the top of the reactor vessel and replace 'spent' pebbles, which are removed from the bottom of the reactor vessel;

[6] Note that the Chinese version of the PBMR may use a steam cycle, at least for the initial units, in which the helium coolant passes through a heat exchanger in which steam is produced, which would drive a conventional steam turbine.

- Size. A typical PWR or BWR produces an output of about 1000MW (1MW is equivalent to 1 million kilowatts), whereas an individual PBMR unit is expected to produce about 110-165MW;
- Modularity. The PBMR is conceived as modular and its economics are expected to be optimal if built in a group of 8-10 units, sharing some facilities such as the control room. PWRs and BWRs are generally built as individual self-sufficient units or in pairs.

All the major nuclear design countries have pursued high temperature gas-cooled reactor (HTGR) designs (those that use graphite as moderator and helium as coolant although not necessarily the other distinctive features of the PBMR) usually dating back to the 1950s, but none has resulted in a design that was built on a commercial basis. HTGR programmes existed in UK, France and Germany, but were abandoned, while research in Japan and USA continues only at a low level.

The PBMR is based on a German design of plant offered by a company called HTR. This company was based on an amalgamation of work carried out by two mainly German based companies, Siemens and ABB. ABB had built a demonstration plant, THTR 300, which achieved criticality (a sustained nuclear chain reaction) in 1983, but, after a very problematic history during which it operated for the equivalent of only about 30 full-power days, it was formally closed in 1989 because of a mixture of technical and economic issues. THTR 300 was somewhat larger than the PBMR (about 300MW) and also used a conventional steam turbine rather than a gas turbine (the coolant helium passed through a secondary circuit in which the energy was transferred to water) to generate the electricity. However, the 'pebble' fuel design was essentially the same as that expected to be used in the PBMR.

The PBMR has been under development in South Africa since about 1993, although it was not until 1998 that these efforts were publicised. Eskom formally took a license with HTR for pebble bed technology in 1999. The terms of this technology license have not been made public and the technology license is not discussed in the FEIR or the DFS. However, typically, a technology license would give the licensor a fee based on units sold, some rights over the new technology, and over the markets in which it could be sold.

It was expected in 1998 that work on construction of a demonstration plant would begin in 1999 and be complete before 2003 to allow commercial orders soon after (see D R Nicholls, 2000). Eskom projected that the market would be about 30 units per year, about 20 of which would be exported. In April 2000, the South African Cabinet approved Eskom's continuation and completion of a Detailed Feasibility Study (DFS) on the proposed PBMR. Subsequently, Eskom formed a company, PBMR (Pty) Ltd to develop and market the technology. PBMR (Pty) Ltd foresaw four phases: research and development (already then completed), feasibility study (then underway), demonstration, and commercial application.

Since then, the timetable has slipped so that the Demonstration Plant, to be built at Koeberg, is not now expected to be in service before 2010 at the earliest.

4.2 The commercial arrangements

The PBMR was developed within Eskom until June 2000. Then British Nuclear Fuels Limited (BNFL), a UK government owned company active in all major aspects of nuclear power from reactor sales and servicing, fuel manufacture, wasted disposal etc became the first foreign investor in the project taking a 22.5 per cent stake in the venture. They were quickly followed by the US electric utility based in Philadelphia, PECO, taking 12.5 per cent of the venture. Subsequently PECO merged with another utility, Commonwealth Edison, to become Exelon. The South African government-owned Industrial Development Corporation (IDC) took 25 per cent of the venture leaving 40 per cent with Eskom of which 10 per cent was reserved for an Economic Empowerment Entity, but this has not been taken up. The agreement left all the shares in PBMR (Pty) Ltd in the hands of Eskom Enterprises, a subsidiary of Eskom, but committed the partners to provide funding in proportion to their stakes in the business to the end of the feasibility phase. Then, the company would be reconstituted in preparation for the demonstration phase with the partners entitled to take a stake in the new company equal to their percentage contribution to the feasibility phase. The costs of development would be recovered as royalties from reactor sales. It is not clear whether partners that did not take up their shareholding in the reconstituted company would be able to recover their share of the development costs, for example, by selling their rights to a third party.

David Nicholls, formerly PBMR project manger in Eskom, was the first Chief Executive Officer of PBMR (Pty) Ltd. He was succeeded in this post by Nic Terblanche, also previously with Eskom, when Nicholls moved back to Eskom in August 2003. In August 2004, Jaco Kriek from IDC replaced Terblanche and Alastair Ruiters of the South African Department of Trade & Industry became the Chairman.

4.3 The cost of development

The DFR (PBMR (Pty) Ltd, 2002a, p 19) reported that costs of development to end April 2001 were R437m. with a further R80m approved in May 2001. It stated that further funding had been approved in December 2001, but the sum was not specified. In the FEIR, PBMR (Pty) Ltd (PBMR (Pty) Ltd, 2002b, p 200) said that the total amount that had been spent on the PBMR to July 2002 was R684.2m and forecast that the total amount to take the project to the end of the feasibility stage (then expected at end 2002) would be R1013m of which R461m would be provided by Eskom.

However, in August 2003, Terblanche[7] stated that PBMR development had cost R1.5bn of which R550m had come from Eskom, a total of R240m from IDC and BNFL with the balance coming from Exelon. BNFL and IDC appear to have spent much less than they were required to, Exelon spent significantly more and Eskom a little less. The additional money had been spent on further design work and letting a number of design and supply contracts. Since then, expenditure has continued on a short-term basis but it is not clear who has funded it, nor what the total development costs to date are.

Terblanche[8] indicated that monthly costs were 'a lot more than' R50m even at the reduced level of activity that had prevailed since the completion of the feasibility phase. Assuming costs were just R50m per month this would mean the development costs to the end of October 2004 were in excess of R2bn. In October 2004, the government announced support of up to R500m for the PBMR venture to pay for running costs for the company and design development costs (turbine development and construction of a helium test facility were mentioned as particular requirements).[9]

[7] Nucleonics Week August 28, 2003, p 1.
[8] Financial Mail, March 26, 2004, p 14.
[9] Business Day, October 29, 2004 and Nuclear News November 2004 / Business News N°51 / 04

However, while this announcement was interpreted as government backing for the demonstration phase, these costs are most appropriately categorised as part of the feasibility phase. In February 2005, when the government's budget was announced, the government support had increased from R500m to R600m. It is not clear whether this government money was a loan or a grant or whether it represented an increase in the government's stake in the PBMR project. It remains uncertain who will fund the demonstration phase.

Overall, substantial sums have been spent on developing the PBMR, about two thirds of which was South African public money. However, the next phase of demonstration will take the level of spending to a far higher level, requiring at least seven times as much money as has been spent so far.

5. The economic aspects

For commercial facilities, those able to survive on the commercial income received, the issue of economic impact is relatively easily bounded. But, for the Demonstration Plant, which by its nature will not be profitable in isolation, the issues are broader and the data subject to a much greater level of uncertainty because of the technological immaturity of the plant design. To evaluate the economic impact of the PBMR Demonstration Plant it is useful to divide the analysis into the costs, risks and benefits of the Demonstration Plant and those involved with the commercial programme.

The main factors that must be considered in the economic analysis of the Demonstration Plant are:

- The partners, especially foreign companies;
- Safety licensing;
- Construction cost and cost of other new facilities required;
- The cost of capital;
- The plant's maximum electrical output;
- Operating performance especially reliability;
- Operations & maintenance cost, including fuel supply and spent fuel disposal;
- Decommissioning cost; and
- Operating life.

Since the Demonstration Plant will not be an economic source of power, it is necessary to estimate who will bear the losses that the Demonstration Plant will incur: taxpayers, electricity consumers or private investors? As well as estimating the value of the economic parameters it is essential to try to estimate the risks that economic performance will be worse than forecast and again, who will be liable for the costs of worse than expected performance. Of course, it is theoretically possible that performance will be better than forecast, but the history of nuclear power contains very few examples of plants that were built ahead of schedule, or with lower than forecast costs, or better than expected reliability.

The analysis for the commercial programme must be much wider ranging and include:

- The economic competitiveness of the PBMR compared to other electricity generation technologies in different markets;
- The likely world market for the PBMR;
- The South African market for PBMRs

None of these factors can be estimated with any precision at this stage and the analysis of risk and who will bear the cost of poorer than expected performance is particularly important.

Despite the legal requirement to demonstrate the 'economic sustainability' of the project, the PBMR's FEIR (PBMR (Pty) Ltd, 2002b, pp 144-202) contains only about 60 pages out of a total of nearly 500 pages on the economic aspects. Of these 60 pages, most of them are devoted to impacts on spatial planning, tourism and supply side management, with only about 10 pages explicitly covering the PBMR. Little of the information needed to assess the costs of the Demonstration Plant and the prospects of success of the subsequent programme is provided and it is necessary to look at other sources to try to glean the necessary information.

It is particularly regrettable that a report by an international Panel of Experts commissioned by the Department of Minerals & Energy (DME) to review the overall project has not been made public in any form. The report was expected to inform a Cabinet decision on the PBMR project. This Panel of fifteen international experts reviewed the overall case for the PBMR as presented in the Detailed Feasibility Study in 2001/02. They were given full access to all information they required and submitted a report to the DME in early 2002. The author of this paper was one of two experts assigned the task of reviewing the economic case.

However, the Panel members were required to promise not to disclose any information they learnt through their meetings and their report has not been made public. All the information presented here is available in publicly accessible sources. Panel members were assured by the DME that Eskom and PBMR (Pty) Ltd would not have access to their report, so it would appear that the only people that have seen the report are DME officials and Cabinet Members. PBMR (Pty) Ltd and Eskom cannot therefore claim that any of their evidence in the FEIR was endorsed by the DME review panel. Note that the DEAT also established a Review Panel to review the Draft Scoping Report for the EIR. The DEAT Panel was entirely separate from the DME's Panel, but like the DME's Panel, its report does not appear to have been made public.

It is difficult to know how the South African public can participate meaningfully in a decision on the PBMR if they do not have access to the most authoritative independent report on the project, that of the DME's International Panel. This need for information is strong because South African taxpayers and electricity consumers have funded most of the development work so far, and it seems likely they will bear an even higher proportion of the much greater costs and risks of building the Demonstration Plant. If the project proves a failure in the long-term, it will be the South African public that will end up bearing much of the cost.

There may, in some instances, be a case to withhold information contained in the Panel report or required to demonstrate the economic sustainability of the PBMR project from the public on grounds of commercial confidentiality. However, since the public is providing much of the funds the presumption should be that all information should be released and the onus should be on PBMR (Pty) Ltd to argue the case specifically where it does believe information should be withheld.

6. Demonstration Plant costs

6.1 The partners

Introducing partners to the venture has three main potential advantages:

- Sharing of development costs;
- Introduction of new skills; and
- Access to foreign markets.

The downside of having partners would be that any benefits to Eskom and the South African public would be diluted, so ideally any foreign partners should bring more than just finance to the project. Eskom brought in three partners in 2000: IDC (25 per cent), BNFL (22.5 per cent), and Exelon (12.5 per cent) leaving Eskom with 40 per cent. Eskom's partners in the development phase have fulfilled their obligation to the programme and have no further legal commitment to fund the programme, leaving the project entirely in the hands of Eskom Enterprises, although the partners will be entitled to take shares in a newly constituted PBMR company if the demonstration phase is launched.

Exelon's main contribution to the project was its promise to open up the North American market. Exelon committed to pilot the design through safety certification by the US Nuclear Regulatory Commission (NRC). Certification by the NRC (or a national regulatory authority with a comparable level of expertise and prestige) will be essential for sales to most markets outside South Africa, not just sales to the USA. Exelon also pledged to buy 10 commercial units and suggested they would buy 40 or more units in the first decade of the commercial phase. The 10 initial sales were the only apparently firm sales for the PBMR there have been (sales to Eskom are conditional on it being the cheapest generation option). These sales would have been an excellent 'shop-window' for the technology for the potentially huge US market and would allow the setting up of reactor manufacturing facilities, which subsequent commercial sales could take advantage of. As an electric utility rather than a plant designer, Exelon's technical contribution to reactor design was limited but as an experienced nuclear power user, its input would have still have been valuable.

Exelon left the project in April 2002 and, while the FEIR explains Exelon's departure on grounds of it not wishing to be a 'reactor supplier' (PBMR (Pty) Ltd, 2002b, p 192), there seem to be additional factors behind their withdrawal. The decision to enter the venture appears to have been very much a personal one by the CEO of PECO, Corbin McNeil (later joint CEO of Exelon). When he left the company, the commitment to the PBMR was quickly withdrawn.[10] John Rowe, the new CEO of Exelon was quoted as saying: 'the project was three years behind schedule and was "too speculative,"'[11]. He also said: "a detailed review that Corbin 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." Since then, schedules have slipped substantially further, probably by more than a further three years. Despite claims by Eskom and PBMR (Pty) Ltd that a large number of interested replacement investors existed, no replacement for Exelon has been found.

[10] 'Corbin was the cheerleader for this technology, and without him, it can't go forward.' Electricity Daily, April 17, 2002.
[11] Energy daily, April 24, 2002.

BNFL entered the venture at about the same time as Exelon and their technical contribution appears to have been in fuel manufacture. At the time they joined the venture, BNFL's Westinghouse reactor vendor subsidiary does not appear to have been involved in the decision and it is not clear whether Westinghouse has had a major input to reactor design. BNFL would provide no significant advantages in terms of access to markets.

BNFL has been in severe financial difficulties for a number of years. In fiscal year 2002, it lost £2.32bn (R25bn) and in fiscal year 2003, it lost £1.09bn (R12bn). It had liabilities of about £30bn (about R350bn) with few assets available to discharge these liabilities. In July 2003, UK government plans to part-privatise the company were abandoned and a major part of its business, waste disposal, reactor operation and reprocessing is to be taken away from it and placed in a new government agency, the Nuclear Decommissioning Agency. The UK government is currently reviewing the future of its other activities. In June 2005, the British government announced it was looking to sell the Westinghouse reactor vending, nuclear fuel manufacture and reactor servicing activities leaving BNFL as primarily a clean-up company. A number of companies are reported to have expressed an interest, including Areva and GE, although by August 2005, only Mitsubishi had made a bid.[12] It is expected that completion of the sale would take until mid-2006.

It appears that BNFL's primary motivation for getting involved with the PBMR was selling fuel rather than reactor sales. Whichever the case, the management that will be responsible for BNFL's contribution to the PBMR is far from certain to be able to continue the commitment even if they wish to. Terblanche has said that BNFL could take 10-12 per cent of the next phase or 25 per cent of the fuel business.[13] This appears unduly optimistic and BNFL/Westinghouse management is not in a position to make such a commitment on behalf of the new owners.

IDC appears to have brought only finance to the venture. As it is owned by the South African government, in terms of risk reduction to the South African public, it contributed nothing. Terblanche was quoted in August 2003 as saying the IDC would take no more than 12.5 per cent of the next phase.[14] However, following a government review in January 2004, IDC is expected to take a more prominent role in the project, and in November 2004, the CEO of Eskom told the Parliamentary Portfolio Committee on Trade & Industry that IDC would be replacing Eskom as project leader.[15] It has been reported elsewhere that Eskom wants to take about 10 per cent of the PBMR Company in the demonstration phase.[16] Kriek has said that he expects the South African public sector to retain at least 51 per cent of the project through Eskom, IDC and the government.[17] On present evidence, it seems unlikely that private investors willing to take the remaining 49 per cent of the project can be found. So, as a minimum, the South African public will be asked to pay for at least half of the R14.5bn the next phase was forecast to cost in August 2005. If costs escalate or private partners cannot be found, the cost to the South African public will be much higher.

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[12] Nucleonics Week, July 14, 2005, p 1.
[13] Nucleonics Week, August 28, 2003, p 1.
[14] Nucleonics Week, August 28, 2003, p 1.
[15] Sunday Times, November 10, 2004.
[16] Financial Mail, December 3, 2004, p 14.
[17] Financial Mail, December 3, 2004, p 14.

A number of other potential investors have been mooted and Eskom has had discussions with the French company, Areva, since February 2004. Areva is a publicly owned company with similar interests to BNFL. However, it has its own HTGR technology, which differs significantly from the PBMR (the fuel is prismatic rather than pebbles) and which Areva claims is superior to the PBMR.[18] It does not seem likely that the two technologies could be readily merged. Areva has shown no indication of being prepared to give its technology up in favour of the PBMR. It has also indicated that it is not prepared to fund the Demonstration Plant. Its interests and its potential contribution appear very similar to those of BNFL and it may not be possible to accommodate both in the next phase even if either company was interested and had the scope to participate.

A number of other potential investors have been mentioned, but these appear to be highly speculative and by far the most realistic investors in the next phase are the existing investors with Areva as an outside chance.

The expected sale of Westinghouse may restrict the possibilities and it seems unlikely that the companies owning the world's two largest nuclear vendors, Framatome and Westinghouse, would want to co-operate even if such an arrangement was acceptable to the competition authorities.

Required information

A realistic assessment is required of what the probability of attracting funds other than from South African public sources is. An assessment of what advantages and disadvantages any identified partners would bring is also required.

6.2 Licensing efforts

It is acknowledged by all sides that for sales to most markets outside South Africa to be possible, certification by a highly experienced, high credibility nuclear safety regulatory agency is required. This is not to denigrate the competence of the South African regulatory authorities, but reflects the risk aversion of electric utilities and those that supply finance to power station construction particularly as electric utilities are exposed more to investment risk. One of Exelon's main contributions to the venture was their role in piloting the design through the US NRC procedures. The NRC had begun to review the design and had collaborated with the South African National Nuclear Regulator (NNR) on design issues but when Exelon withdrew, the NRC quickly wound down licensing activities.[19] It has been reported that PBMR (Pty) Ltd officials met with NRC officials in October 2004 to discuss design progress[20] but it does not appear that NRC is carrying out any substantial design evaluation.

Without NRC approval for its design, it is not clear that the Demonstration Plant would have much value in promoting foreign sales. Until the design had been approved by the NRC and finalised, construction cost of the commercial export design cannot be estimated accurately. If the Demonstration Plant design differed significantly from what was required by the NRC (for example if the Demonstration Plant was built without a pressure containment and the NRC indicated it would require one for any plant built in the USA) potential buyers would see construction and operation of the Demonstration Plant as having only limited demonstration value

[18] Nucleonics Week, March 25, 2004, p 6.
[19] Inside NRC, May 20, 2002, p 4.
[20] Nucleonics Week, November 4, 2004, p 1.

Required information

The FEIR should state what strategy has been developed to obtain internationally credible regulatory clearance for the commercial PBMR design and how this would fit in with the Demonstration Plant.

6.3 Construction cost and cost of associated facilities

Repaying the cost of construction of the plant has always been expected to be the major element in the overall cost of power from any nuclear power plant. Its importance has increased in the last decade as attempts to introduce competition to the electricity industry have increased the cost of capital raising the charge for repaying the construction cost.

The FEIR contains no information on the expected construction cost of the Demonstration Plant or on the commercial plants. It merely states: 'The cost to build the PBMR demonstration module will probably be available on completion of the project business plan (year end 2002).' The DFR contained no details on the cost of the Demonstration Plant.

In 1999, Nicholls (Nicholls, 2000) forecast that the construction cost would be about US$100m (then equivalent to about R600m) for a single commercial module, presumably as one of 8-10 units installed on one site. The strategic importance of this estimate was that it placed the price of the PBMR at around the US$1000/kW of installed capacity, a level above which it was widely assumed that nuclear could not compete with gas-fired technology.[21]

Nicholls[22] was quoted separately as estimating the cost of the Demonstration Plant as double the settled down commercial cost with a further US$100m for a fuel sphere production plant. The total cost of the Demonstration Plant was therefore then estimated to be about US$300m or a little less than about R2bn.

In 2002, the DFS (PBMR (Pty) Ltd, 2002b, p 23) suggested some cost increases had occurred and the target construction cost for commercial units was now placed at US$1000-1200/kW. However, there appear to have been major cost increases. These have been masked by three factors. First, it is not clear whether the current cost estimates cover as full a range of costs as the original estimates, for example, if the cost of the first fuel load was omitted (conventionally this is included in the construction cost), the apparent cost would fall masking real cost increases. Also, it is also not clear whether the new estimates are now a cost or a price (i.e. including the profit). Second, there has been some depreciation (about 10 per cent) of the Rand against the US dollar between 1998 and 2004. However, the third factor is the most important. In 1998, the design was expected to produce a net output of 110MW but commercial plants are now expected to have an output of 165MW, an increase of 50 per cent. This would allow the cost of a module to rise by 50 per cent without increasing the cost per kW.

In September 2001, Nicholls[23] admitted the original schedule for the Demonstration Plant had slipped. He then projected start of construction for 2002, with completion

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[21] The US Department of Energy's New Generation Nuclear Plant programme launched in 2002 has a target capital cost of US$1000/kW for new nuclear power plants. The PBMR (Pty) Ltd Feasibility Report (PBMR, 2002b, p 23) notes a target price of US$1000-1100/kW.

[22] Nucleonics Week, October 14, 1999, p 7.

[23] Nuclear News, September 2001, p 35.

expected in 2005 and commercial sales to begin in 2009. There was discussion about up-rating the output of the plant to 130MW to be achieved without significant cost increases.[24] The Chief Executive of one of the partners in the project, Corbin McNeil of Exelon, was quoted in the same article as saying the upper limit on output was 150MW but he assumed the final figure would be 130MW. McNeil also stated the cost of the first module had risen to about US$300m. This article also acknowledged delays in the design work particularly with the turbine and the graphite liner.

In 2002, the DFR, (PBMR (Pty) Ltd, 2002a, p 50) stated the design could be up-rated to 137MW 'without a significant increase in cost'. This meant that costs per module could increase by nearly 20 per cent whilst still remaining within the US$1000/kW target.

In April 2002, Exelon withdrew from the PBMR venture[25], although it agreed to fulfil its commitment to fund the venture until completion of the feasibility study phase, then expected to be finished in September 2002. Forecast start of construction of the Demonstration Plant had by then slipped to 2004.

By May 2002, Nicholls[26] was much less precise in his estimate of the cost of the Demonstration Plant, estimating a cost of between US$2000-5000/kW. At the bottom end of the range, assuming a unit size of 110MW and US$2000/kW and an exchange rate of US$1=R6, this would translate into a total cost of R1.3bn, while at the upper end, with 130MW and US$5000/kW, it would translate into R4bn. It is not clear whether these estimates included the cost of a fuel production facility. Nicholls still adhered to the US$1000/kW estimate for commercial orders provided these were built in groups of 8-10 per site and only after 20 units had been sold.

By December 2002, the target output of commercial units had increased to 165MW, 50 per cent higher than originally planned. Nicholls[27] admitted that the US$1000/kW would not be achieved until 32 units had been sold. Further delays were announced in the programme. Earlier in 2002, the shareholders of PBMR (Pty) Ltd had expected to announce whether they would proceed beyond the feasibility stage by the end of 2002. This decision was postponed into an unspecified date in 2003 and appeared still not to have been taken in December 2004. In July 2003, the Demonstration Plant was expected to be 125MW with subsequent units producing 165MW.[28]

A particular issue was the supplier of the gas turbine. This would be the first-of-a-kind and would be the first commercial gas turbine to use helium gas as the energy carrier (normally gas turbines are driven by the exhaust gas from the combustion of the oil or gas fuel) and represents a significant engineering challenge. The contract to design the turbine was originally placed with the French company, Alstom but they were replaced in 2001 by Mitsubishi for unspecified reasons. It is not clear how far development problems with the gas turbine have delayed the programme and have increased costs. In November 2004, PBMR (Pty) Ltd announced a major design change in the gas turbine moving to a horizontal turbine generator set rather than the three-shaft vertical configuration that had been planned.[29] It should also be noted that the frequency of the North American electrical system is 60Hz, compared to 50Hz in

[24] Nucleonics Week, October 11, 2001, p 1.
[25] Nucleonics Week, April 18, 2002, p 1.
[26] Nucleonics Week, May 2, 2002, p 10.
[27] Nucleonics Week, December 19, 2002, p 1.
[28] Nucleonics Week, July 3, 2003, p 1.
[29] Africa News, October 29, 2004.

Europe and South Africa. China is 50Hz, but Japan is part 50Hz and part 60Hz. This means the speed of rotation of the gas turbine is different and generally gas turbines that produce power at 60Hz are of a significantly different design to those that produce power at 50Hz. It is not clear who would pay the cost of development of 60Hz machines for exports to the USA.

The main extra cost for the demonstration programme apart from the generating plant itself was the fuel manufacture plant expected to be built at Pelindaba. In 1999, Nicholls estimated this would cost about US$100m (R600m) but more recent forecasts for the demonstration programme have not separated the fuel plant from the reactor, so it is impossible to determine how far escalation in the cost of the demonstration programme has been the result of increases in the cost of the fuel plant.

Once the end of the feasibility phase had been reached, the partners' commitment to fund the venture came to an end and essentially PBMR (Pty) Ltd had no further guaranteed access to funding. It was planned that in the demonstration phase, PBMR (Pty) Ltd would be reconstituted and the previous partners would have the right to take up a shareholding in proportion to the funding they had provided for the feasibility phase. It is not clear how PBMR (Pty) Ltd has been funded since the end of the feasibility phase. It appears most likely that a combination of government and Eskom money has allowed PBMR (Pty) Ltd to continue operations, albeit on a severely reduced scale.

By August 2003, PBMR (Pty) Ltd was seriously short of cash and was appealing to the South African government for support.[30] A review of the project was begun by the government in January 2004 and it gave PBMR (Pty) Ltd 'two months to propose a way forward for the PBMR.'[31] The Demonstration Plant was then projected to cost US$1.3bn (R8bn) and it was still hoped to begin site work at the Demonstration Plant in 2004. In March 2004, Terblanche estimated the cost of the Demonstration Plant would be R10bn and it could not be in full operation before 2010, implying a 2007 construction start and the launching of commercial sales after 2012.[32] Ferreira[33] broadly confirmed these figures in September 2004.

However, a August 2005 Ferreira confirmed that the estimated cost of the demonstration phase had increased again to R14.5bn.[34] If this increase of nearly 50 per cent in a little over a year is confirmed, this would add to the evidence that costs are seriously out of control. It is not clear whether the US$1000-1200/kW estimated cost for commercial units still stands.

In the period 1999-2005, the estimated cost of the demonstration programme appears to have escalated by a factor of more than seven. Until the detailed design is completed: equipment design development, for example on the turbine, has been carried out; design approval by the National Nuclear Regulator (NNR) is given; and the plant has actually been built, the cost estimates must be treated with scepticism. Experience with other nuclear projects shows these processes provide ample scope for further major cost escalation.

[30] Nucleonics Week, August 28, 2003, p 1.
[31] Nucleonics Week, September 2, 2004, p 5.
[32] Financial Mail, March 26, 2004, p 14.
[33] Nucleonics Week, September 2, 2004, p 5.
[34] Business Day, August 16, 2005, p 2.

A particular regulatory issue is that of containment/confinement to the reactor. The containment serves to prevent the contents of the reactor escaping into the environment if there is an accident in the reactor or if there is an external accident, for example, an aircraft hitting the plant. The arguments are complex, but, in essence, it is argued (PBMR, 2002b, p 29) that a pressure producing accident is implausible so an expensive pressure-retaining containment would not be necessary. PBMR (Pty) Ltd argues that a containment that need only withstand, for example, aircraft impact would be much cheaper.

In September 2003, a spokesman for the NNR said '"At this stage, we don't have the answer" about whether a pressure-resistant containment is required, the NNR executive said. "It's a long shot to say the regulator has accepted" that confinement suffices.'[35] However, PBMR (Pty) Ltd (for Eskom) not only has to convince the South African NNC, it also has to convince a high credibility international regulator, most likely the US Nuclear Regulatory Commission (NRC). It would make no economic sense nor would it be politically acceptable for PBMR (Pty) Ltd to design one model for South African use and another (apparently safer) for international orders. So until this issue is resolved, there must be a significant risk that construction cost estimates will increase. The issue of containment is by no means the only significant licensing issue still to be resolved.

Required information

An up-to-date estimate of the cost of the Demonstration Plant is required, broken down into the cost of the plant itself, the fuel supply plant and any other significant facilities. An analysis of the cause of the delays to the programme and of the factors behind the massive cost escalation that has occurred is required. An analysis of the remaining risks of cost escalation, for example from design changes, unexpected equipment development problems, should also be provided.

6.4 The cost of capital

While the construction cost of the plant has been of continual concern, there has been little debate about the cost of capital. Traditionally, the cost of capital for power plants was very low, typically a real annual rate of 5-8 per cent. This low cost of capital reflected the fact that, as monopolies, electric utilities were generally able to pass on whatever costs they incurred to consumers, so there was very little risk that the loan would not be repaid. Of course, this did not make constructing new power plants a low economic risk, it simply meant that electricity consumers were bearing the risk rather than the company. Also government-owned utilities were regarded as being fully underwritten by government and the credit rating of government owned utilities was generally the same (very high) as that of the government itself and the cost of borrowing correspondingly low.

In the past decade, with the opening up worldwide of the electricity industry to competition and the privatisation, at least in part, of many utilities, the position has changed dramatically. Many electric utilities, the potential customers for the PBMR, have been privatised and wholesale electricity markets introduced. This is planned to take place in South Africa with the splitting up of Eskom into regional distribution companies, a transmission company and a requirement to sell 30 per cent of its generation. This plan, notably the sell off of generation, appeared to be under review

[35] Inside NRC, September 22, 2004, p 8.

in October 2004 and it may be that Eskom will continue to be able to pass on the costs of its investments to consumers no matter how ill-conceived these decisions turn out to be.

However, in other markets, investment in generating plants is now a high risk to the owners of companies and the companies providing them with finance. The privatised utilities can no longer rely on government backing to support their credit rating. In Britain, the country that pioneered electricity privatisation and opening to competition of electric utilities, this risk is very real. In 2003, about 40 per cent of Britain's generating capacity was owned by financially distressed companies.[36] Half of this capacity was the nuclear plants while the rest was a mixture of coal and gas-fired plants. At one point, the second largest owner of power plants in Britain was the consortium of banks that had lent money to investors and had repossessed the plants when they began to lose money.

Even before this stark demonstration of the economic risk of owning power plants, the real annual cost of capital for new generation plants in Britain was in excess of 15 per cent compared to about 6-7 per cent for investment in the parts of the industry that remained a regulated monopoly (essentially the distribution and transmission networks). In developing countries where currencies are less stable, there would be an additional risk premium on capital and, for example, the real cost of capital in Brazil would be at least 20 per cent. Given that repaying the capital charges is the largest element of the cost of nuclear power, it is easy to see if this cost is increased by a factor of 2-3, the impact on the economics of nuclear is going to significant and probably disastrous.

Nicholls (Nicholls, 2000) used a real cost of capital of 6 per cent and although this appears to have been increased to 8 per cent for subsequent analyses, this is far below the level that will be applied in many of the PBMR's target markets.

A decision to allow use of too low real cost of capital would have significant consequences, especially in a country like South Africa that has limited access to capital and very heavy demands for public spending in areas such as health and education where the returns on investment would be high and the risks low. Using capital on a low-return, high-risk project like the PBMR would risk crowding out more attractive and socially useful projects.

The issue of rate of return was raised by the Legal Resources Centre (Register of Comments (2002), 28.137), but the response suggests the person replying either did not understand the question or chose not to answer it: 'The PBMR project has been thoroughly evaluated by the respective investors on a commercial basis. Although their required Return on Investment (ROI) varies, normal commercial benchmarks were used in this evaluation process.'

Required information

The FEIR economic assessment should specify and justify the cost of capital that will apply to the Demonstration Plant and the associated facilities

[36] S D Thomas (2004) 'Evaluating the British model of electricity deregulation' Annals of Public and Cooperative Economics' 75, 3, 367-398.

6.5 Maximum electrical output

There has been considerable confusion about the output of the Demonstration Plant, which has been variously reported as 110MW, 125MW, 137MW and 165MW. The DFR (PBMR, 2002a, p 25), stated the Demonstration Plant would be 110MW but would be modified in service to produce 125MW. The extent of the modifications necessary was not specified. It was implied that the first 10 commercial units would produce 125MW, but later units would produce 137MW. The DFR spoke of a later move to a core producing a thermal output of 400MW core and improvements in the conversion efficiency so that this would generate 200MW of electricity. The design changes necessary to achieve the 137MW output were expected to be such that earlier units could not be retrofitted to produce this higher level of output. In September 2003, Nicholls[37] was quoted as saying the Demonstration Plant would produce 125MW, while a year later, Nucleonics Week[38] reported 'the first unit would be limited to 110 MW'. In November 2004, Nucleonics Week[39] reported the thermal output of the plant would be 400MW, sufficient to generate 165MW. It reported: 'Eskom will file for revision of the EIA to take account of the higher electrical capacity' after final Record of Decision (ROD) was given.

This confusion needs to be resolved to clarify exactly what the Demonstration Plant will prove. Up-rating the output of a plant by 50 per cent is clearly not a trivial step and the International Panel discussed in detail the implications of the increase from 110MW to 125MW. If the design of the Demonstration Plant is significantly different to that of the commercial units, there must be doubts about how far the Demonstration Plant will indeed be a useful demonstration of the technology. Alternatively, if the design is the same but only operating at two thirds of its capability, potential buyers may not be convinced that the Demonstration Plant does demonstrate the commercial technology.

Clarification is also needed on how far regulatory approval for a 110MW unit would be transferable to a 165MW unit. In this context it should be noted that Westinghouse obtained regulatory for its new AP600 design in 1999 but this design proved not to be economic. Westinghouse up-rated the output by about 50 per cent to gain scale economies and had to begin again the process of gaining license approval in March 2002 for the replacement AP1000. Final approval by the US regulatory body, the NRC, is not expected before December 2005.[40]

It is not clear how far the up-ratings to the PBMR are due to simple changes to optimise the output of the plant (for example, operating at a higher temperature) and how far it is due to attempts to use scale economies to compensate for failing economics. It should be noted however that the design taken on from HTR produced a thermal output[41] of 226MWth, this was up-rated to 265MWth, then 300MWth and now commercial plants are expected to produce more than 400MWth, an increase on the original design of nearly 80 per cent.

[37] Nucleonics Week, September 25, 2003, p 10.
[38] Nucleonics Week, October 7, 2004, p 3.
[39] Nucleonics Week, November 4, 2004, p 1.
[40] Nuclear Engineering International, October 2004, p 5.
[41] Only about 40% of the thermal energy is converted into electricity.

Required information

Clarification is required on the expected output of the Demonstration Plant, how the design will relate to that of any subsequent commercial units. In particular it should show extent to which the Demonstration Plant will 'demonstrate' the commercial technology and how far safety licensing for the Demonstration Plant will be applicable to the commercial units.

6.6 Operating performance

For any technology with high up-front costs, operating reliability is essential for good economic performance. To illustrate this, let us assume that the load factor[42] of a nuclear plant is expected to be 90 per cent and at this level, fixed costs will represent two thirds of the overall cost of power per kWh. If load factor is actually 60 per cent, this alone will raise the overall kWh cost by a third. Extra repair and maintenance costs to reflect the issues that produced this poor performance will increase costs even more.

Reliability of nuclear power plants worldwide has been extremely variable and has generally been well below the levels forecast. For example, the Dungeness B nuclear power plant in Britain, which was selected ahead of other options partly on the basis that it would have a high lifetime load factor of 85 per cent has, after 20 years of operation, a lifetime load factor of only 36 per cent. The two existing Koeberg PWR units, also after nearly 20 years of operation, have lifetime load factors of only about 65 per cent.[43]

Nicholls[44] forecast that the lifetime load factor of the PBMR would be 94 per cent. This is hard to justify on a number of grounds. First, it would make the PBMR more reliable than any operating reactor worldwide. In 2004, the best lifetime load factor for any nuclear plant was 93.5 per cent and only 6 out of more than 400 operating units had achieved a lifetime load factor over 90 per cent. Second, much is made by PBMR (Pty) Ltd and Eskom of PBMR's ability to 'load-follow', in other words vary its output as demand changes (PBMR (Pty Ltd, 2002a, p II and PBMR (Pty) Ltd, 2002b, p 24). Clearly if the units are operating at below their design rating 'load-following' for any significant part of the year it will be impossible to achieve load factors as high as forecast and the economic performance will be similarly reduced. The ability to load-follow would be an optional feature that would also increase the construction cost.

For the Demonstration Plant, it might be expected that reliability would be poorer than for commercial units partly because of the need to carry out testing and demonstration activities, and partly because the Demonstration Plant will inevitably throw up technical problems that will only become apparent when a real plant is actually operated, and these will require shutdown for repair. If operating performance is expected to be significantly poorer than for the commercial units, this will make the power from the Demonstration Plant very expensive because the fixed costs will be spread over fewer saleable units of electrical output

[42] Load factor is calculated as the saleable electrical output of a plant in a given period (usually a year, or over its lifetime) as a percentage of the output it would have produced had it operated at its full design output rating uninterrupted.
[43] See Nuclear Engineering International, August 2004, p 38.
[44] Nucleonics Week, November 19, 1998, p 1.

Operating performance

The forecast load factor for the Demonstration Plant should be specified and justified, and its impact on the cost of power identified.

6.7 Operations & maintenance cost

There is a common perception that once a nuclear power plant is built, the electricity is essentially free. Nuclear plants are assumed to be largely automatic and fuel costs are assumed to be low. While fuel costs are generally low, operations & maintenance (O&M) costs can be high. For example, a number of US nuclear power plants were closed down in the 1990s because it was judged it would be cheaper to pay the cost of building and operating a new gas-fired plant than paying the cost of simply operating an existing nuclear plant. Since then extensive efforts have been made in the USA to reduce costs. The USA is the only country to publish properly accounted O&M costs. In 2003, the cheapest plant to operate generated at about US 1.2c/kWh (US cents) of which, about US 0.4c/kWh was fuel cost. The most expensive plant cost US 2.6c/kWh and the median was about US 1.65c/kWh.

No estimates of the operating cost of the PBMR have been published but Nicholls (Nicholls, 2000) estimated fuel costs at 0.4c/kWh, comparable to US figures. Given that in the same paper he forecast that total generating cost would be US 1.43c/kWh including repayment of capital, it seems likely Nicholls assumes the non-fuel O&M costs will be negligible. Given the non-fuel O&M costs alone for US plants average about US 1.2c/kWh, this assumption seems highly optimistic and cannot be accepted without detailed justification.

Required information

The O&M costs for the Demonstration Plant should be specified and justified, broken down by fuel and non-fuel costs.

6.8 Decommissioning cost

Decommissioning is an immensely complex area that cannot be fully covered here. If the South African government allows the PBMR project to proceed to the demonstration phase, it is important to note that this commits it not just to the cost of the facilities required, but also to pay for the decommissioning of the Demonstration Plant and other associated facilities such as the fuel manufacturing plant.

Decommissioning has significant economic, ethical and social dimensions as well as technical aspects. It is assumed that the ‘polluter pays’ principle should apply to the funding of decommissioning and this means:

- There should be clear plans to return the site to ‘green-field’ status after plant closure and decommissioning, i.e., the land should be fit to be released for unrestricted use including food production;
- Those that consume the electricity from the plant should pay for its decommissioning. This is generally done by creating a ‘segregated’ account[45] that accumulates funds provided by consumers throughout the life of the plant to pay for its ultimate decommissioning;

[45] A segregated account is one which the owner of the plant cannot draw on and as a result, if the owner of the plant fails financially, the decommissioning provisions are not lost.

- Provision needs to be made for large scale waste disposal to deal with the large amounts of radioactive material generated during decommissioning;
- Clear plans need to be put in place to document the location of all radioactive materials and plant design so that those that decommission the plant have full knowledge of what they will encounter;
- Careful ongoing monitoring of skills availability needs to be carried out to ensure that vital skills remain available until decommissioning is complete. This is particularly important where a long delay between plant closure and completion of decommissioning is anticipated. For example, in the UK it is planned to delay completion of decommissioning until more than 100 years after plant closure.

In one respect, the polluter pays principle cannot be followed. There is no way to prevent a future generation having to carry out the potentially dangerous task of decommissioning nuclear power plants.

Decommissioning is conventionally assumed to be carried out in three phases: removal of fuel; removal of uncontaminated or lightly contaminated structures; and removal of contaminated structures, essentially the reactor itself. From a purely economic viewpoint, the incentives are always to carry out stage one as quickly as possible. A plant with nuclear fuel in it must be fully staffed because of the risk of criticality and once the fuel has been removed, the staffing level can be significantly reduced saving the labour costs. The economic incentives are to assume as long a delay for stages 2 and 3 as possible. Any fund created to pay for decommissioning will have longer to earn interest, reducing the provisions consumers must make to achieve the required sum. In practice, social and technological factors may over-ride this incentive. For example, it may be politically unacceptable to leave a potentially hazardous facility in place for several decades simply to allow the fund to accumulate sufficient interest to pay for decommissioning.

The DFR (PBMR, 2002a, p 27) anticipates two possible strategies, early plant dismantling or 'safe enclosure', in which stages 2 and 3 would be delayed. The DFR does not specify the length of the delay, but it should be noted that the THTR plant in Germany is expected to be in safe enclosure for at least 30 years. The DFR states that: 'if the demonstration module is not successful, the plant will be mothballed in 'safestore' until the decommissioning of Koeberg I and II. However, negotiations with Eskom in this regard have not been finalized.'

Typically, it is assumed that the cost of decommissioning represents about a third of the construction cost. Since the decommissioning cost clearly has little direct relation to the construction cost, this indicates the immaturity of decommissioning technology and the only plants fully decommissioned worldwide are not representative. For example, they may have operated for only a short time and are little contaminated, or the plant may have been disposed of in a large hole without dismantling (Trojan, USA) or the plant is very small.

The FEIR (PBMR (Pty) Ltd, 2002b, p 201) states that 1.5 per cent of the capital cost is provided for decommissioning. It is not clear what is meant by this. Subsequent clarification by consultants (Register of Comments, 2002, 28.149) has suggested that: 'the PBMR Operator will provide 1.5 per cent of the capital cost of the plant on an annual basis over the useful life of the plant.' And that the proposed minimum provision would be based on a 15 per cent of original yet escalated, construction costs, (sic) be made available for decommissioning at the economic end of the plant (Register of Comments, 2002, 28.149).

This is still far from clear and the reliance on estimating the decommissioning as a percentage of the construction cost betrays the fact that little work has been done on estimating decommissioning costs. The FEIR does specify that a segregate (sic) fund will be set up.

Experience with the plants of similar technology to the PBMR in Germany is particularly salutary. The 15MWth pilot AVR plant (it produced heat but no power) is of similar technology to the PBMR and operated from 1967-88 before engineering problems caused its closure. The estimated cost of decommissioning and dismantling the AVR escalated from about €20-million during the early 1990s to as much as €490-million in 2002 (about R7bn).[46] So even after closure of the plant, decommissioning costs were subject to huge price escalation and if any provisions had been collected, they would have proved totally inadequate, leaving later generations to meet the cost.

The THTR 300 demonstration plant, also using pebble bed technology, was in service for only six years to 1989 but produced minimal amounts of power and is therefore likely to be lightly contaminated. It was de-fuelled only in 1995, placed in 'safe enclosure' in 1997 and it is not expected that decommissioning of the contaminated parts of the plant will start before about 2020. No recent cost estimates for decommissioning have been published. Again, if it had been assumed the plant would operate for, say 20 years and decommissioning provisions had been collected from electricity consumers on that assumption, any provisions would have been totally inadequate.

For a demonstration plant, which inevitably has a very uncertain length of operating life, it would seem more prudent to include the necessary provisions in the initial cost to reduce the risk of a shortfall in decommissioning funds if the plant operates for a shorter period than expected.

Required information

The estimated decommissioning cost for the Demonstration Plant should be published broken down into the three main stages. The assumed timing of the three phases should also be specified and the arrangements for funding the process (how the money would be collected and kept, what rate of interest is assumed) given.

6.9 Operating life

The expected operating life of the plant will determine how long the owner has to repay the construction costs. The longer the life, the lower the annual repayments are. In practice, expected operating life is not as important as might be expected. Generally, commercial loans do not have a repayment period longer than 20 years so this is the maximum 'amortisation' period for a commercial facility.

Nicholls (Nicholls, 2000) projected a 40-year life for a commercial PBMR module. This would appear to be rather optimistic. No estimate has been given for the Demonstration Plant's lifetime. Demonstration plants often have quite a short life because they tend to be expensive to operate and once they have demonstrated (or failed to demonstrate as in the case of THTR 300) the technology, they are retired to reduce the losses consumers must bear. This is of particular concern if the

[46] Nucleonics Week, July 18, 2002, p 2.

decommissioning provisions are collected over the forecast operating life of the plant and this forecast proves too long.

Required information

The FEIR economic assessment should specify and justify the expected economic life (the time over which construction costs will be recovered and decommissioning provisions collected) of the Demonstration Plant

6.10 Who will pay the extra cost of the Demonstration Plant?

It is clear that the overall cost of power from the Demonstration Plant will be much higher than the current average cost of power to South African consumers. Foreign partners would be unlikely to want to subsidise power to South African consumers. There are plans to break Eskom's effective generation monopoly, selling off some of their plant to competing companies. In this situation, Eskom is unlikely to want to be saddled with an uneconomic generating plant when it cannot pass on the additional costs to consumers. The DFR (PBMR, 2002a, p 32) states: 'Eskom will, upon successful commissioning, purchase it from PBMR (Pty) Ltd on normal commercial terms. The cost of development of the PBMR technology and generic design, as well as the up-front programme development costs, will therefore not be recovered through the sale of the demonstration plant, and will be capitalized in the books of the proposed PBMRCo enterprise for amortization over the 25-year review period'. It is not clear what 'normal commercial terms' means. It could mean: paying the forecast cost of a commercial PBMR plant; paying the equivalent cost of the cheapest generating option; paying the full cost of the Demonstration Plant, minus some development costs and the cost of the fuel plant.

No mention is made of the operating costs. It could well be that with a relatively small fuel plant, operating unreliability and inexperience with operating PBMRs, the operating costs could be higher than those of, say, a coal plant. In this situation, Eskom would be left with a facility that would not be economic to operate even on a marginal cost basis and it would be left unused.

In evidence to the South African Parliament's Minerals and Energy Affairs Portfolio Committee, the CEO of Eskom, Thulani Gcabashe, only committed that Eskom would 'host' the demonstration unit.[47] It remains to be seen whether government is willing to provide subsidies or whether it will try to force Eskom to pass the extra costs on consumers.

Required information

The FEIR economic assessment should indicate precisely what Eskom will be expected to pay for the Demonstration Plant, how much the additional cost of power from the Demonstration Plant over and above the cost that would have been incurred if the power had been generated by commercial plants will be and who will pay these additional costs.

6.11 Analysis of risk

The PBMR project has always been a high-risk project. Thomas (Thomas, 1999) writing in 1999 said:

[47] Sunday Times, November 10, 2004.

> ‘The development of the PBMR by Eskom would represent a highly risky venture which would be underwritten by tax-payers and electricity consumers.’

These risks have been amply demonstrated over the following six years. The cost of the Demonstration Plant has increased by a factor of more than seven and completion of the Demonstration Plant, expected in 1999 to be in 2003, is now still at least five years off. If the risks had, by now, all been incurred, this poor history of technology development would be of limited relevance to the decision whether to go ahead with the Demonstration Plant. In economists’ jargon, ‘bygones are bygones’. In other words, the development costs have been incurred and cannot now be ‘unspent’: what matters for decisions being taken now are the remaining costs and risks. Of course the failure to control costs and the huge slippage in the time-table must be taken into account in judging the competence of the developers, PBMR (Pty) Ltd and the likelihood that the remainder of the programme can be completed to time and cost.

The previous analysis has shown that there are still many risks. The design is far from complete, for example, a major change to the turbine generator design was announced in October 2004, the design has not received South African NNR approval, nor has substantive progress been made with approval by the US NRC. Even when these processes are complete, the history of nuclear power amply demonstrates the large risk of cost escalation during the construction phase. So the risk that costs will escalate even further is high. The statement in the Register of Comments (Register of Comments, 2002, 28.144) that ‘the PBMR detailed design has been finalised.’ cannot be justified. Since then, the turbine generator design has been changed, the plant output upgraded, apparently requiring significant design changes and until NNR approval is given, clarifying, for example, whether a pressure containment is needed, the design cannot be regarded as finalised. The problems in completing the design also do not provide confidence in the abilities of PBMR (Pty) Ltd nor do they augur well for the technological success of the Demonstration Plant.

Attempts to reduce the risk to the South African public have had some success, with about a third of the development cost in the feasibility phase being met by foreign companies, notably Exelon, but also BNFL. However, for the much more expensive (at least seven-fold) demonstration phase, Exelon will not participate and BNFL seems unlikely to be in a position to make a substantive contribution. Attempts to bring in other foreign investors, such as US utilities, the French company Areva and Chinese interests have not yet succeeded and it now appears likely that if the Demonstration Plant is to go ahead, it will be largely underwritten by South African public money through the government, Eskom, or IDC. This will include not only the estimate of at least R14.5bn to build the plant and associated facilities, it will also include the cost of decommissioning the plant and the extra cost of buying the electrical output over and above the cost of generating in commercial power stations.

The FEIR was seriously inaccurate even before it was published. It acknowledged the withdrawal of Exelon but the sales projections were still heavily dependent on Exelon. Exelon would buy the first commercial unit, before Eskom, and in the crucial first five years of the commercial phase when the business has to establish itself, it assumed Exelon would buy half the units sold. In the three years since the FEIR was published, the date when the first commercial units are expected to be sold has slipped by eight years and no replacement for Exelon has been found. Inevitably, the pressure is on Eskom, underwritten by South African taxpayers and electricity consumers, to step in to fill the gap.

6.12 The cost of a catastrophic accident

This report does not examine the costs that would arise if the Demonstration Plant were to cause a catastrophic accident. However, it should be noted that the 1986 Chernobyl accident in Ukraine is expected to result in costs of US$235bn in the 30 years after the accident.[48]. It is therefore essential that the promoter's claims that such an accident is totally impossible should be evaluated fully, and if the probability is not zero, consideration needs to be given on how such astronomic costs could be met.

6.13 The cost of waste and spent fuel disposal

This report does not examine the cost of waste and spent fuel disposal. However, a number of points should be made.

First, worldwide, no spent fuel has been disposed of yet. All fuel used to date remains in temporary surface stores or has been reprocessed to produce plutonium. Note that reprocessing does not reduce the amount of waste to be disposed of,[49] it merely splits it up into different 'packages'. Until facilities have been designed and built that give the public full confidence that spent fuel can be disposed of in such a way that there is no risk that this material will be exposed to the human environment over the millions of years that it will take for the material to become harmless, the costs must be regarded as speculative.

Second, worldwide, very few waste disposal facilities for low-level and intermediate-level waste have been built in recent years and the waste that is being disposed of is mainly going to old sites designed fifty or more years ago. Until there is more evidence of the cost of designing, building and operating waste disposal facilities that meet current safety standards and are publicly acceptable, the cost of waste disposal must also be regarded as uncertain.

Third, as with decommissioning, the cost of waste and spent fuel disposal will be incurred decades after the waste is created. If funds are put aside at the time the waste is created, these funds can be invested and can be expected to grow substantially. For example, a fund that is invested for 40 years, earning an annual real interest rate of 2.5 per cent will grow by a factor of 2.7. However, this does point to the need to establish clear procedures to take money from consumers to pay for these activities and to keep it in secure investments so the risk that it is lost is minimised.

[48] http://www.chernobyl.info/index.php?userhash=745163&navID=34&lID=2
[49] In fact, reprocessing produces a large volume of additional low-level and intermediate-level waste because all the facilities and chemicals used in reprocessing become contaminated.

7. The commercial programme

Construction of the Demonstration Plant only makes sense if there is a high probability that it will lead to a profitable (to South African interests) stream of orders for commercial PBMRs. It is therefore essential to examine the prospects for such sales if the economic case for the Demonstration Plant is to be properly assessed.

7.1 The economic competitiveness of the PBMR

The economic competitiveness was assessed in detail by the International Panel of experts in 2002 and their report would provide a proper basis to analyse the economic prospects for the PBMR programme. The estimates given by Nicholls in 2000 (Nicholls, 2000) are clearly out of date. The information required for commercial units is:

- Construction cost;
- The cost of capital;
- The plant's maximum electrical output;
- Operating performance especially reliability;
- Operations & maintenance (O&M) cost, including fuel supply and spent fuel disposal;
- Decommissioning cost and;
- Operating life.

In some cases, for example, maximum electrical output, the information will comparable for all markets, but in others it might vary. For example: PBMR (Pty) Ltd might sell units to Eskom at a discount to the cost other customers; construction cost will vary depending on how many units are being built on the site; the cost of capital will vary from country to country according to the commercial position of the customer and the economic conditions in the export country; operating performance will vary according to whether the plant is expected to be base-load or load-following; decommissioning cost will vary according to the cost of waste disposal in the country of installation.

A key assumption will be the construction cost. Let us assume the Demonstration Plant alone (not including the fuel plant) will cost about US$1.5bn (two thirds of the R14.5bn that the demonstration programme was estimated to cost in 2004) or about US$13,600/kW if the plant produces 110MW, the gap to commercial units costing US$1000-1200 is huge. If the design can be stretched to produce 165MW at no extra cost, the cost per kW would be about US$9000/kW. This still leaves a huge reduction in costs to get down to the target levels. Some of this will come from not having to incur the technology start-up costs the Demonstration Plant would require. The rest must come from various scale economies and learning effects. These include: building ten units on a site; scale economies in manufacturing if a minimum number of units are sold. The DFR did not publish any details of these scale economies claiming the information was commercially confidential (PBMR (Pty) Ltd, 2002a, p 56)

Required information

The government should publish the report by the international Panel of Experts. Eskom should publish the latest cost and performance estimates for the commercial plants as well as the assumptions on factors such as cost of capital by market. It should also specify how the unit cost is expected to be reduced by a factor of at least nine from the Demonstration Plant to a fully commercial unit.

7.2 The likely world market for the PBMR;

PBMR (Pty) Ltd and Eskom have always been very vague about target markets and countries as wide-ranging as Chile, Cyprus, Turkey, Saudi Arabia and Egypt have all been mentioned as possible targets. There appears to be little basis for this speculation and these markets should be discounted until there is some substantive evidence to back them up.

The DFR (PBMR (Pty) Ltd, 2002a, p 50) is ludicrously over-optimistic, given the absence of anything remotely close to a firm order, suggesting that: 'the sale of PBMR plants and fuel is more likely to be constrained by supply capacity limitations than by demand.' It backs this up saying:

> The market analysis shows that the potential exists for the market to conservatively absorb up to 235 five-pack plants (1 175 modules) over the two decades following the start-up of the demonstration plant. This represents only 3.3 per cent of the world demand for new generation capacity. Notwithstanding this excellent potential, the base-case sales scenario adopted in the enterprise business plan forecasts the sale of only 258 modules over the evaluation period of 25 years, and is therefore conservative.

Despite the fact that Exelon had already withdrawn from the project when it was published, the FEIR (PBMR, 2002b) still anticipated commercial sales beginning in 2006 with 15 units going to Exelon in the period 2006-8 and a total of 44 units by 2017. Eskom sales were expected to be at a much slower rate, starting in 2007, completing the 10-unit order by 2012 and ordering a total of 20 units by 2017. Other customers were expected to buy 76 units by 2017. So in the first 12 years of the commercial phase, the FEIR forecast sales of 140 units, a slightly faster rate of sales than the DFR.

Given that over the past decade, the volume of nuclear plant ordered has been only one or two 1000MW units a year, this seems far from conservative. In fact, it seems clear that PBMR (Pty) Ltd has carried out no detailed market analysis on a country-by-country basis and projections are simply an arbitrary percentage of an overall market for power plants. This issue was raised by LRC as Comments on the DFR (Register of Comments, 2002, 28.137) but the response does not make much sense and does not answer the question. It states;

> The market studies were based on 53 plants, only one of which is to be sold to Eskom. Thorough market studies were done as part of the business case. We are not sure on what the statement "it seems likely that the world market for nuclear power may be no more than 1 or 2 units per year" is based, especially since the world market for new power stations is about $70 million per year.

No mention is made elsewhere of 'the market studies of 53 plants'. Since $70 million would only, on PBMR (Pty) Ltd's figures, cover about half the cost of one PBMR module, it is not clear what the response means.

The fact that a significant percentage of the market is effectively closed to nuclear power by political decision is not taken into account. Even so, it should be noted the DFR represents a significant downgrading of sales forecasts to about 10 units a year from earlier when Nicholls (Nicholls, 2000) forecast 30 units per year.

This weakness was acknowledged by the new CEO of PBMR (Pty) Ltd in September 2004 when he said there was a need for 'a "much more detailed marketing strategy" with "a strong focus on customers' needs. He said marketing strategies would be tailored to a given country or customer, versus a more generic strategy followed in the past.'[50]

Such studies would quickly reveal that for much of the world, new orders for nuclear plants are not feasible. In Europe, many countries have made a decision not to build nuclear power plants, e.g., Austria, Denmark, and Norway or are phasing out nuclear power, e.g., Germany, Italy, Sweden, Belgium the Netherlands and Switzerland or not expanding existing capacity, e.g., Spain. The UK government carried out a review of nuclear power in 2003 and found no case for new nuclear power orders. France decided in November 2004 to build a new nuclear power plant of a French design, EPR, a 1500MW design based PWR technology, and it seems highly unlikely it would abandon this in favour of the PBMR. The medium-term prospects for PBMR sales in Europe therefore appear minimal.

In the USA, PBMR (Pty) Ltd's hopes were based on Exelon getting license approval for the PBMR and launching the commercial programme by ordering 10 units. It is clear this will not happen now and while some utilities offer supportive statements to the technology, as expressions of intent to buy plants, these are essentially worthless.

For example,[51] the CEO of Exelon (John W Rowe) was reported in May 2005 that:

> 'the high price of natural gas is an incentive to build new plants, but that an offsetting factor is the continuing low cost of coal. The lack of a solution for nuclear waste is also a deterrent.'

While the CEO of Dominion, another large US utility often mentioned when new nuclear orders are mooted said

> "We aren't going to build a nuclear plant anytime soon. Standard & Poor's and Moody's would have a heart attack," said Mr. Capps referring to the debt-rating agencies. "And my chief financial officer would, too."

The main expected export market therefore appears to be China, but despite several years of discussions, China has made no commitment to South African PBMR technology. Tsinghua University has the only operating PBMR in the world, a 10MW unit that went critical in 2000 using German fuel technology. Tsinghua University is collaborating with US interests from the Massachusetts Institute of Technology on a competitor to the South African PBMR.[52] Overall it is far from clear who Chinese companies will choose to collaborate with, but all experience shows that Chinese interests will try to 'indigenise' any technology they pursue so even if they do collaborate with PBMR (Pty) Ltd, and orders are placed, South African content to these sales would low and the net benefit of these sales to South Africa small.

It seems more likely that China will produce its own design of PBMR, similar to that of PBMR (Pty) Ltd, which would supply any sales in China and would compete with the South African design in world markets. Nucleonics Week reported in June 2005 that Tsinghua University's Institute for Nuclear & New Energy Technology (INET) expected to complete the design for a commercial scale of plant (about 195MW) by 2006 and have a plant in operation by 2010.[53] These forecasts may be no more realistic than those of its South African counterpart but the intention to develop an independent design rather than import technology is clear.

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[50] Nucleonics Week, September 2, 2004, p 5.
[51] M. Wald, 'Interest in Reactors Builds, But Industry Is Still Cautious' New York Times, May 2, 2005, p 19.
[52] Nucleonics Week, November 6, 2003, p 1.
[53] Nucleonics Week, June 23, 2005, p 8.

If a world market for high temperature gas-cooled reactors does develop, as well as competition from a Chinese vendor, the South African PBMR may face competition in international markets from the US vendor General Atomics and from Areva, companies that are both developing designs using prismatic fuel.

General Atomics supplied the demonstration HTGR built in the USA (Fort St Vrain) and has the advantage of being US-based and therefore politically well-placed to receive US government funds. Areva has less experience with HTGRs but its huge experience in reactor design and sales gives it advantages in international markets.

A pre-condition for any international sales appears to be obtaining safety approval from the US NRC. Without a US partner and with no sales in prospect, it is not clear why the USA should spend US taxpayers' money reviewing the PBMR design. If PBMR (Pty) Ltd is to obtain licensing approval in the USA, it seems a large proportion of the cost will therefore have to be borne by PBMR (Pty) Ltd.

Required information

The Applicant should publish the PBMR (Pty) Ltd's marketing plan and its strategy for gaining license approval from the US NRC in the FEIR

7.3 The South African market for PBMRs

In the absence of foreign markets, this leaves Eskom as the most likely customer. Eskom has committed to build and operate the Demonstration Plant. It has said it will buy 10 units, but only 'provided it's the lowest-cost alternative at the time the utility needs to add capacity'.[54] Note that the DFR (PBMR (Pty) Ltd, 2002, p 50) misleadingly does not include this caveat on cost, saying only: 'Eskom has provided PBMR (Pty) Ltd with a letter of intent covering the purchase of a demonstration plant and 10 further units.'

Eskom does not say in the FEIR whether, on current expectations of cost of a commercial unit it expects the condition that it be the 'lowest-cost alternative' to be met. Eskom should provide a detailed analysis of the economic conditions that would have to be met, including costs of the alternatives, such as coal, gas and renewables, as well as the cost of the PBMR, for the PBMR to be the cheapest alternative.

Given that commercial orders cannot be placed before about 2013, such calculations are highly speculative. In that time frame, it cannot be assumed that Eskom will exist in anything like its present form and the attractiveness of alternative technologies, such as gas-fired plant and renewables could have changed dramatically.

In the second half of 2004, pressure on Eskom to commit unconditionally to buy several commercial units increased. In October 2004, Kriek said the PBMR (Pty) Ltd's business plan 'envisages Eskom committing up front to some 4,000 MW of PBMR capacity in South Africa, which would allow "economies of scale" and development of a commercially competitive product.'[55] This plan appeared to be endorsed by the government Minister for Public Enterprises, Alec Erwin, in his mid-term budget statement of November 26, 2004, when he said: 'plans include the additional generation of 4,000MW to 5,000MW of electricity from pebble bed units located around the country.' Tom Ferreira, communications manager for PBMR, said that around 4,000MW of electricity could be met by 24 PBMR units each with a

[54] Nucleonics Week, August 28, 2003, p 1.
[55] Nucleonics Week, October 7, 2004, p 3.

generating capacity of 165MW. If the cost of these units was no more than the target cost of US$1000/kW, this would mean that Eskom was being asked to commit to making an investment of at least R25bn before the technology was economically or technologically proven. It seems highly unlikely that the units bought by Eskom could be sold at this price and the figure of R25bn is therefore at the bottom end of the likely costs.

However, the signs are that Eskom itself wishes to distance itself from the project. The forecast time when new generating plant will be urgently needed is difficult to predict because of uncertainties about demand growth rates, the degree to which old plants can be refurbished and mothballed units returned to service. Steve Lennon, Eskom's MD for resources and strategy suggested that 1000MW of new peaking capacity (power stations only required for times of peak demand) would be needed each year from 2005-09 with base-load capacity (power stations that operate throughout the year) needed from 2010 onwards.[56] Clearly the PBMR, which cannot be in service as a commercial option before 2015[57] at the earliest, is of little relevance to this immediate need for new capacity.

The managerial changes in PBMR (Pty) Ltd in August 2004 when an IDC executive, Jaco Kriek, became CEO and a Department of Trade & Industry Director-General, Alastair Ruiters became Chairman, replacing the predecessor from Eskom, Nic Terblanche were reported as being 'intended to get the project out from under the management of South African utility Eskom**,** which does not want to be in the business of developing new nuclear technology.'[58]

This very much echoes the position taken by Exelon in 2002 when they withdrew from the project. These changes seem to be supported by the government. Nucleonics Week[59] reported:

> Up to now, the chairman of Eskom Enterprises, Eskom's subsidiary for unregulated industry, has automatically held the PBMR chairmanship, but now it's not even certain that Eskom will be represented on the board. An informed source said the government is "not eager for Eskom to continue as an investor and a potential customer," in part because that would inevitably lead to conflict-of-interest situations.

The CEO of Eskom confirmed this interpretation in evidence to the South African Parliament Portfolio Committee on Minerals and Energy. He said the IDC was to take over the leadership of the PBMR programme. Eskom would be "playing a lesser role (as a PBMR investor) as we go forward, because we are now going to take the role of customer".[60] He also seemed to suggest that the PBMR should not go forward without foreign investors. He said more international investors were needed "to be able to advance to the stage where we can construct the demonstration unit and have it commercially proven" and that Eskom would "dilute" its participation as an investor in the PBMR, and allow other investors to be brought in. He also seemed to confirm that PBMR would have to be the cheapest option if Eskom was to buy it: 'if all of our

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[56] Financial Mail, December 10, 2004, p 36.

[57] The Energy Minister, Phumzile Mlambo-Ngcuka said in August 2004 that 'the pebble-bed modular reactor was at least 10 years away from becoming a commercially viable project'. Business day, August 16, 2004, p 2.

[58] Nucleonics Week, August 26, 2004, p 7.

[59] Nucleonics Week, September 2, 2004, p 5.

[60] Sunday Times, November 10, 2004.

technical and commercial criteria are met, we'll be taking the first set of units that are produced.'[61]

The South African government affirmed in October 2004 its commitment to open up the electricity generation sector to foreign investment. The Trade & Industry Minister, Alec Erwin[62], suggested that about a quarter of the investment needed up to 2009 would come from companies other than Eskom. This effectively removes from Eskom the obligation to ensure there is sufficient generating capacity for the country. It also in effect places Eskom in a competitive market. In this situation, it would be unreasonable to expect Eskom to compete with new generators if it was obliged to buy a number, specified by the government, of PBMRs regardless of whether they were the cheapest option or whether they were even required. The only logical commitment Eskom can be asked to make is that it orders PBMRs when it needs new capacity, provided it is the cheapest option available. In practice, this is a largely empty commitment because, if when it needed new capacity the PBMR was the cheapest option, it is hard to see why Eskom would not order it.

When the PBMR project was launched, it was expected to be primarily an export project producing about 30 units per year, with two thirds of the units for export. Thomas argued (Thomas, 1999) that the world market forecast was implausible and no more than one or two units per year would be sold. Six years later, the overall world market for nuclear power plants looks no more promising and PBMR (Pty) Ltd has failed to identify any firm prospects export sales.

Required information

The FEIR should specify what obligation Eskom has to purchase commercial PBMRs.

7.4 Benefits to the South African economy

The PBMR programme has always been sold to the South African public as a generator of jobs and wealth. Nicholls (Nicholls, 2000) suggested that the programme would generate 204,546 jobs and additional annual GDP of R18331m (the apparent precision of these inevitably highly speculative forecasts is grotesque). This was on the basis of a total market of 30 units per year, 20 of which were for export a local content of 50 per cent and 10 of which were for South Africa with local content of 81 per cent. The DFR (PBMR (Pty) Ltd, 2002a, p 55) projects annual sales of 10 units with local content for South African units of 69 per cent (48 per cent for the Demonstration Plant) and for export units, the South African content would be 43-65 per cent depending on the market (developed or developing country) and on how many units were sold. These are no more than targets and the actual percentage would be negotiated on an individual basis. If the market for PBMRs was disappointing or a large market was opening up, it may well be necessary to accept lower percentages rather than jeopardising sales. For example, China would be likely to require a very high local content.

Clearly the lower forecast sales volume and local content figures will dramatically reduce the jobs and economic effects forecast by Nicholls in 2000, perhaps by 75 per cent and the DFR showed figures of 63,719 jobs and GDP of R8522m (again grotesquely over-precise).

[61] Sunday Times, November 10, 2004.

[62] Business Day, October 27, p 2.

However, it is necessary to look at how these figures were generated. The DFR projects a unit cost for commercial units of about R180m. It forecasts that 40 permanent jobs will be created at the Demonstration Plant site plus about 1400 local construction jobs for about two years. The number of people working in manufacturing plants is forecast to be about 450 (PBMR (Pty) Ltd, 2002b, p 191). If we assume local content is on average about 60 per cent, this means the direct value to South Africa of 10 orders per year would be about R1000m. The number of direct jobs created would be of the order 1000.

It is therefore clear that projections of 60,000 jobs and GDP increase of R8.5bn must be based on 'second round' effects of jobs created in the companies servicing the PBMR programme, for example the steel industry might be able to sell some more steel and in jobs created servicing the needs of the workers employed. Complex computer models of the economy as a whole are used to model these effects but the results should be treated with care (see PBMR (Pty) Ltd, 2002a, p 55-62). Any large programme of spending, if fed into this type of computer model, would produce large numbers of extra jobs and a large amount of extra GDP. For example, if the South African government embarked on a large programme of construction of pyramids, this would generate new wealth and jobs perhaps in the cement and construction sector, but the money would be entirely wasted because the pyramids would be useless. The export orders for the PBMR would generate no permanent jobs in South Africa for operators, and few if any temporary jobs for construction workers, while the pressure from customers would be to maximise their local content, so factory jobs (and second round effects on supplying industries such as the steel industry) would be much less than forecast.

Required information

Eskom should specify how many jobs will be directly created by the programme, for example as plant operators and manufacturing plant employees, specifying the assumptions that lie beneath these forecasts.

7.5 Risk analysis

The risk has always been that if international orders did not materialise, the South African public would be required to bail out the project by placing uneconomic orders. Thomas in 2000 wrote (Thomas, 2000):

> However, what will happen if Eskom does go ahead without major international collaborators and the stream of orders does not materialise? Will South African politicians have the nerve to write off the project or will plants be built ahead of need in South Africa just to keep the capability in existence? National flagship projects have a tendency to live long after they should have been killed off and South African consumers will end up paying for a series of expensive white elephants.

Even if the Demonstration Plant appears to be technologically successful (it will take several years of reliable operation before risk-averse foreign utilities will be convinced of this), that is no guarantee of international sales. PBMR (Pty) Ltd's cost projections for the commercial units are based on very large and still entirely speculative scale economies. If these are not realised, the commercial design would not be competitive.

The government appears to be acting to take control of the PBMR project away from Eskom, with IDC taking the lead role, while attempting to oblige Eskom to buy the plants. Eskom is being asked to invest more than R25bn in a technology for which the design is not even complete, let alone demonstrated and proven. To some extent, these changes will be of limited interest to the South African public. From a theoretical point of view, if the government is going to oblige Eskom to build more PBMRs than would be economically optimal, it should reimburse Eskom from taxes. However, the public may be largely indifferent whether they pay extra to subsidise PBMRs through their taxes or through their electricity bills. It will be much more concerned about the potential huge loss of public money.

8. Conclusions

The National Environmental Management Act (NEMA) requires developers to demonstrate that their projects are economically sustainable. To judge economic sustainability, it is necessary to look at the life-cycle costs of the Demonstration Plant for the Pebble Bed Modular Reactor (PBMR). The Final Environmental Impact Report (FEIR) does not provide sufficient data to assess these. However, given that by its nature, a demonstration plant will not be economically viable in isolation, to judge whether the expenditure on the next phase is justified, it is also necessary to look at what the prospects of success for commercial PBMR units are.

Eskom and PBMR (Pty) Ltd are keen to justify the Demonstration Plant on grounds of forecast benefits of a programme of commercial PBMR orders to the South African economy in the FEIR and the associated Detailed Feasibility Report (DFR). However, the FEIR does not provide any information on the economics of a commercial programme and in the responses to comments on the Draft EIR (Register of Comments, 2002), the consultants refused to answer questions on the programme stating 'the present EIA is limited to a single demonstration module PBMR'.

However, it is possible to draw conclusions on the economic sustainability of the Demonstration Plant and on any subsequent commercial programme by drawing together the information supplied by Eskom and PBMR (Pty) Ltd officials to various news media.

8.1 The Demonstration Plant

Conclusion 1: Regardless of its success or otherwise, the Demonstration Plant will leave a substantial liability that will fall on South African public funds caused by the need to decommission the plant and the associated facilities, and to pay for the disposal of the spent fuel. The FEIR and the DFR do not quantify these liabilities, providing no information on spent fuel disposal and no usable information on expected decommissioning cost. However, experience in other countries suggests that decommissioning costs could be of the same order of magnitude as construction costs.

Conclusion 2: Since details of the project were made public in 1998, costs of the Demonstration Plant have escalated by a factor of more than seven. The project lead-time has slipped so that it is now apparently further away from commercial exploitation than it was in 1998 when commercial orders were forecast to take place from 2003. Now, seven years on, commercial orders are not forecast for about ten years. This shows that the developers failed to understand the scale and nature of their task. There is still considerable scope in the next phase for further cost escalation and delay due to changes to the design and construction problems. The developers' poor record to date gives little confidence in their ability to control costs and time schedules in the next, more expensive phase.

Conclusion 3: Forecasts of other economic parameters, such as operating performance, operating cost and decommissioning cost have not been updated since 1998 and appear implausibly optimistic. It is understandable that developers of a project have an optimistic view of the project's prospects – 'appraisal optimism'. However, investment decisions should be taken on the basis of sober, unbiased judgements of the most likely outcomes, not the views of the project's promoters.

Conclusion 4: PBMR (Pty) Ltd successfully diversified some of the risk away from the South African public for the feasibility phase with foreign partners, Exelon and

BNFL Ltd, sharing the costs. However, the cost of this phase (about R2bn) was far more than forecast and the absolute amount paid for by the South African public was not reduced. PBMR (Pty) Ltd has spoken optimistically over the past three years about the prospects of recruiting new partners to replace Exelon and BNFL (if as seems likely it cannot participate), but nothing has come of these negotiations. Until there is solid evidence of new partners being bought in, it must be assumed that the cost of the demonstration phase will fall substantially on the South African public, through Eskom, IDC, or direct government subsidies.

8.2 The commercial plants

Conclusion 5. PBMR (Pty) Ltd's analysis of the world market for PBMRs is simplistic, taking no account of any of the commercial or political factors that would apply in key export markets. A particular concern is finance for export orders. This is an important issue for developing countries, which are likely to account for a significant proportion of the forecast orders. Such countries frequently have difficulty financing large investments. The World Bank and most other International Financial Institutions do not provide finance for nuclear investments. The South African PBMR could face strong competition from other types of high temperature reactor, notably a very similar Chinese design and models offered by Areva and the US company, General Atomics. Until a rigorous market analysis has been carried out and subjected to independent scrutiny, and arrangements for helping finance export orders made explicit, PBMR (Pty) Ltd's assumptions on the likely world market have no basis.

Conclusion 6. Pressure is mounting on Eskom to commit to buy large numbers (24) of commercial units even before the technology has been technically and economically proven at a cost in excess of R25bn. Eskom appears, rightly, to be holding to its position of only buying it if the PBMR is the cheapest option available, something that will not be known until the Demonstration plant is in service and has operated for some time. If Eskom is required to make such an advance commitment, it could be forced to purchase uneconomic plants, raising the price of power to consumers, and adversely affecting public welfare and the competitiveness of the South African economy.

Conclusion 7. The future of Eskom is uncertain. The South African government has been considering reforms to Eskom for a number of years, including its privatisation and its break-up into competing units. There can be no guarantee that in 2013 or later, when the first commercial orders for a PBMR might be placed that Eskom will exist in any recognisable form, much less one that can be obliged to order a particular type of power plant, especially if it does not represent the best commercial option.

8.3 Overall conclusions

Conclusion 8: The PBMR project is a highly risky venture. The feasibility phase has cost more than R2bn, about two thirds of which has been paid by South African public money. Despite this expenditure, there is still ample scope for the project to fail. The next phase will require a much higher level of expenditure, at least R14.5bn, with more than half of this again coming from the South African public. If the project fails, there will be significant consequences for the South African public either through higher electricity prices (if Eskom is forced to bear much of the risk) or through taxation if the government has to write-off the costs.

Conclusion 9: The National Environmental Management Act (NEMA) requires developers to demonstrate that their projects are economically sustainable. The FEIR does not provide the data necessary to make such a judgement. This information strongly suggests there is a high risk that the project will not be economically sustainable. On the available evidence, the project does not meet the requirements of the NEMA and the applicants, Eskom, should not be given approval.

Conclusion 10: The current high fossil fuel prices and the measures to reduce greenhouse gas emissions seem to give a new impetus to generation technologies that do not use fossil fuels. However, it should be remembered that previous oil price spikes (1974 and 1980) were short-lived and resulted in little nuclear investment apart from in France. Investors are unlikely to make multi-million dollar investments in new nuclear power plants on the basis of a short-term oil price spike which could have disappeared long before a nuclear plant could be brought on-line. On greenhouse gas emissions, nuclear power faces competition from renewable technologies and energy efficiency measures, options that generally do not encounter the public acceptability problems that nuclear power suffers from.

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