The PBMR project: an assessment of its economic viability

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SOUTH AFRICA'S ELECTRICITY UTILITY, Eskom, has been aggressively developing the pebble bed modular reactor (PBMR), drawing on high-temperature reactor (HTR) technologies from Europe and the U.S.A. The project has substantial political and marketing support from government. This paper examines the prospects of economic success for the PBMR in the current global market for nuclear reactors. Our analysis shows that considerable technological hurdles remain, and that Eskom is unlikely to be able to export sufficient units for the long-term economic viability of the project. Using Eskom’s cost projections in a simple costing model for nuclear power, we demonstrate significant deviations from international cost data, suggesting that Eskom may be unduly optimistic about the cost of power from the PBMR — further undermining its international marketability.

In April 2000, the South African national electricity utility, Eskom, obtained Cabinet approval to carry out a feasibility study for constructing the prototype of a new design of nuclear power plant, the pebble bed modular reactor (PBMR). Since then, government has supported the project politically, viewing it apparently as significant for the continent’s development through targeted technological initiatives. This paper does not explore the geopolitics of the PBMR project, but focuses on the economic prospects of success.

Eskom has been developing the PBMR design since 1993 at a cost to the company, by late 2000, of R120 m (about $17 m). To bring the PBMR to the point of readiness for commercial sale on the world market will require finance more than an order of magnitude greater, much of which will come from, or be underwritten by, South African electricity consumers and taxpay ers. If the project is successful, Eskom predicts annual export revenues of R18–20 bn. If not, the utility will have wasted billions of rands of public money. This paper examines some of the arguments for and against Eskom’s development of the PBMR, in particular the technology’s reliability, its economic prospects, and its potential markets.

Other criteria for judging the PBMR include plant safety, the environmental impacts (including nuclear waste disposal in particular), and public sentiment. We concentrate, however, on the commercial implications, and, in the context of international experience with nuclear power, on:

- the track record of the technology;
- reasons that electricity ‘privatization’ (or ‘liberalization’) and nuclear power do not mix;
- the economics of nuclear power;
- the impact of safety and regulatory requirements;
- the world market for nuclear power plants and the prospects for South African exports.

Technological reliability

Reliability is critical to any technology’s economic performance. With most successful new technologies, people confidently expect successive designs to become more reliable, to offer better performance, and therefore to become cheaper to operate. With nuclear power, however, costs have risen consistently in real terms despite technological advances, and processes that were expected to prove easy to master continue to throw up technical difficulties. Waste processing and disposal remain neglected problem areas, and the public remains divided about nuclear power’s acceptability as a form of power generation. The ringing promise from 1955 of ‘power too cheap to meter’ returns to haunt the nuclear industry.

There is widening consensus that nuclear power technology faces a crisis: global confidence in it has eroded, mainly through the economic failure of current technology. To revitalize the industry, a new generation of nuclear technology is needed to capture the imagination of engineers, politicians, energy planners and the public, as did the designs of the 1960s.

Eskom openly criticizes the economics of the design of the pressurized water reactor (PWR) it built at Koeberg. This design, and its close relative, the boiling water reactor (BWR), account for the great majority of plants built worldwide. Eskom claims that the technical features of the PBMR — which belongs to a different class of reactors called high-temperature gas-cooled reactors (HTRs) — will solve the main economic problems of PWRs and BWRs by achieving acceptable safety standards at a competitive cost, and by significantly enhancing operating efficiencies. Against a background of failed attempts in Germany, the U.S.A. and Britain to commercialize HTR technology, Eskom, a newcomer to nuclear plant design, may have difficulties in succeeding.

Considerable challenges also arise in ancillary technologies. A nuclear fuel plant would have to be built, probably in South Africa, that manufactures the pebble-shaped fuel to exacting standards. Even the conventional part of the plant, the gas turbine, would be a new product developed at Eskom’s expense. According to Eskom’s publicity material, this part of the plant uses the ‘standard Brayton cycle’, implying a proven standard product. Only one gas turbine using helium has ever been built, however, which had a short life because it failed to operate reliably; it seems reasonable to assume that this type of gas turbine technology still requires considerable further development.

The economics of nuclear power and the PBMR

The following questions should be considered when we assess the likely economics of the PBMR:

- how well does this nuclear technology complement developments in electricity markets?
- is the cost structure of this technology competitive and are the estimated costs realistic?
- will the extra costs resulting from meeting regulatory requirements be manageable?

Nuclear power in a competitive electricity market

Privatization, sometimes called ‘liberalization’ or ‘de-regulation’, is a complex process, with one feature crucial to the PBMR debate. When, through privatization, the generation of electricity ceases to be a monopoly, new competitor compa-
Monopolies operate differently from competitive businesses. In a monopoly, the risk of building new power plants falls on the consumer. If plant construction costs overrun, if the plant is inefficient, or if power stations are built that are not needed, the costs are passed on. A monopoly electricity utility needs sufficient power stations to meet demand, otherwise power cuts occur at great national cost and the utility’s credibility suffers. To minimize this risk, monopolies tend to over-invest in plant. In the 1980s, for instance, Eskom so over-estimated electricity demand that new coal-fired plant had to be mothballed as soon as it had been built, and the cost of this wasted investment fell unwittingly on consumers and taxpayers.

In a competitive situation, utilities that make mistakes lose market share because their plant is too expensive, or they sell power at a loss with the costs falling on shareholders. Utilities therefore choose proven technology for which construction time and costs can be guaranteed, and for which performance can be assured. Since the British electricity industry was privatized in 1990, much new plant has been built, but all of it has used combined cycle gas turbines (CCGTs), largely factory-built from standard components, unlike a nuclear power plant that requires complex on-site assembly. Britain had never considered this option before privatization, but industry found the technology commercially attractive, and secure supplies of the gas needed were available in large quantities at stable prices. Privatized generators in South Africa might well find that, with the possibility of gas-fired generation, similar conditions will arise here, with neighbouring countries eager to exploit their gas reserves.

It is less problematic to privatize companies with existing nuclear plants but no plans for new units, than it is to privatize companies with high-cost expansion plans needing shareholder funding. Many nuclear power plants, if they operate efficiently and require no major repairs, can generate enough income from power sales to cover running costs, but they struggle to make an adequate return on the initial investment. Repaying loans and paying the interest is invariably the largest direct cost in any assessment of the cost per kilowatt-hour of electricity generated from nuclear power.

Privately owned plants that cannot meet their full costs, including capital, are known as ‘stranded assets’. They are either retired — as has happened in the U.S.A. — or their losses are met by subsidy, as was the case in Britain. The owners argue that they built the plants in good faith to meet consumer demand, that the plant-building had met regulatory approval, and that, under the old monopoly system, the owners recovered the full cost from consumers. If competitive electricity generation now prevents plant owners from recovering all their costs, they claim that they should be compensated for the lost income. Compensating the owners of stranded assets in this way is taking place at most U.S. nuclear power plants and in other countries including Spain. They continue to operate, but consumers, having paid for the construction of these uneconomic plants, now pay a surcharge to the plant owners to give them the full level of profit they expected when they planned the facility.

When publicly owned utilities are privatized, stranded assets are seldom identified and electricity consumers and taxpayers unknowingly bear the costs. In Britain, for example, the publicly owned nuclear company, Nuclear Electric, completed the Sizewell B PWR in 1995 at a cost in excess of £3 bn. The company, whose assets included Sizewell B and seven other relatively new nuclear plants, was sold to private investors a year later for £1.7 bn, little more than half the cost of building just one of the eight plants sold. Consumers who paid for and owned these plants saw assets with a replacement value of more than £15 bn sold for barely more than a tenth of that sum.

### Key determinants

The economics of nuclear power is a contentious field. It is difficult to verify independent estimates of construction and operating costs. Furthermore, the results, crucially, depend on accounting and investment appraisal assumptions such as the rate of return on capital that is sought (the discount rate), the loan period, and the assumed lifetime of the plant. The loan period decided by financial institutions (that lend the capital) is determined, amongst other things, by the expected economic lifetime of the plant, and the main element in the costing of each unit of electricity generated is the capital cost of building the plant. The shorter the expected lifetime of the plant and the higher the discount rate, the higher will be the fixed costs. In a monopoly, the assumed life of the plant can be its expected physical lifetime, because the owner can normally run the plant until it wears out. Where there is competition, the plant has to be retired earlier if it cannot compete with new plants. Institutions lending money for new power station construction are aware of this factor and, on these grounds alone, normally want to recover the cost of a new nuclear plant in no more than 15 years.

Government-owned utilities have been able to invest money at very low rates of return on capital, partly because new power stations were seen as a safe investment, and partly because, for various reasons, governments tend to require a lower rate of return on capital than does private industry. Thus in Britain, before privatization, the national utility, the Central Electricity Generating Board, could invest at a 5% real (net of inflation) rate of return and recover the costs over 35 years. After privatization, private investors do not invest in new power plants unless they can make a 12-15% real return and recover their capital over 15-20 years.

The running costs of nuclear power plants are essentially the same whether the plant is operating as a monopoly or with competition. The true costs are often difficult to establish, however, as privatized utilities regard such data as commercially confidential, and monopolies tend to present their investments in a good light by showing low operating costs. In the U.S.A., utilities are required to publish fully authenticated running costs, and these give a useful reference point. In 1998, the operating cost for the cheapest unit was about 1.2 c/kWh (0.75 pf/kWh) and the average was about 2.1 c/kWh (1.3 pf/kWh). Of this, some 0.4–0.6 c/kWh was fuel cost while the rest, 0.8–1.6 c/kWh, represented the non-fuel cost of operation and maintenance (wages, spare parts, etc.). In Britain, the only business of the company that owns the nuclear plants is nuclear power generation, so there is nowhere to hide the costs and these too represent a useful reference point. The total operating cost in 1998 of the seven U.K. privatized nuclear power plants was somewhat higher than those in the U.S.A., and was calculated at about 2 p/kWh.
An illustrative cost model

The effect of changes in the discount rate and the lifetime of the plant on the fixed cost of its electricity can be demonstrated by means of a simplified model that makes the following assumptions:

- the capital investment is repaid in equal annual payments over the lifetime of the plant;
- the average amount of money owed will be half the capital cost; and, therefore
- the average interest paid per year will be the interest payable on half the total cost.

Although crude, this model yields cost estimates of the right order of magnitude and illustrates how changes in key assumptions affect the overall cost of nuclear power. The implications for South Africa are obvious: the economic feasibility of the PBMR project is critically dependent on Eskom's assumptions, whose veracity can be determined only by independent scrutiny of these data.

The model is demonstrated below using the case of Sizewell B and assuming that:

- each kilowatt of capacity at Sizewell cost about £3000 to build and will generate about 6000 kilowatt-hours (kWh) per year;
- the capital costs are recovered over 35 years at an interest rate of 5%.

In this case, the cost in pence per kWh just of repaying fixed costs, and taking no account of running costs, will be:

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\text{Cost per kWh} = \left( \frac{(1500 \times 100 \times 0.05) + (3000 \times 100/35)}{6000} \right) = 2.7
\]

During the public approval process for Sizewell B, however, government realized that the above discount rate was inappropriate. Low-risk investments in other sectors of the economy were yielding 8% real, and to charge nationalized companies less would have been a distortion. It therefore raised the discount rate to 8%; this change alone immediately raised the fixed cost by 25% to 3.4 p/kWh. Repeating the above calculation for an interest rate of 12% and a repayment period of 20 years — generous assumptions in a competitive market — the cost per kWh amounts to 5.5 p. With a 15% discount rate and a 15-year life, the fixed cost rises to 7.1 p/kWh.

To put these figures in context, the total cost (fixed and running) of a new coal plant when Sizewell B was first planned was about 3.5 p/kWh (British coal was then about four times more expensive than South African coal). Hence, if the running costs of U.K. nuclear plants had been as low as those of the best U.S. plants (0.75 p/kWh), and using the original assumptions (5% discount, 35-year cost recovery period, to give a fixed cost of 2.7 p/kWh), Sizewell B might have been economically viable. By the time of privatization, newly ordered gas-fired plants were expected to generate electricity at about 2.9 p/kWh — well below the cost of Sizewell B on these assumptions. However, at an 8% discount rate (the one set by government at the time), the total cost of power from Sizewell B would be perhaps 50% higher than gas-fired generation.

By 1996, the cost of gas-fired plants and of gas had come down and their efficiency had gone up, so that total generation cost dropped to about 2.2 p/kWh. This is a quarter of the cost of nuclear power using the same assumptions on lifetime and discount rate. Subsequent improvements in gas power technology can be expected to have increased the cost differential even further.

The above model also demonstrates the importance of operating performance: if, instead of 6000 kWh per year the plant produced only 3000 kWh, the fixed costs would double. Lower than anticipated output is often a neglected risk in fixed-cost calculations: over its lifetime, the Fort St Vrain demonstration HTR (a 330-MW plant) in the United States averaged only about 1300 kWh per year.

This simple analysis demonstrates that existing nuclear technologies in Britain would produce power so expensively that, without huge subsidies, conventional nuclear plants are not a serious option for any utility. If, for example, U.K. nuclear plants could be built for half the actual cost of Sizewell B and generate 7500 kWh per year, the fixed cost per kWh would still be 75% higher than that of a gas-fired plant. While specific details of the fixed cost structure may vary from country to country, the general characteristics sketched above were probably an important consideration in most countries now turning their back on this technology.

Construction costs in the few countries still developing or maintaining their nuclear programmes (most notably France, Japan and China) may be lower than those used in the analysis above. In France, for example, where large numbers of nuclear power plants have been built, construction costs appear to be much lower than in Britain or the U.S.A. (though the figures are not independently authenticated); there may also be other macro-economic reasons militating against a downturn in nuclear power generation or obscuring the real costs of that energy. Even France, however, is no longer building new nuclear plants. Its last order was placed a decade ago, and the costs of any new orders are likely to be higher than when France’s nuclear construction programme was at its height. The point remains that, even in the most successful nuclear countries, nuclear power appears to be uneconomical in a competitive market.

Testing Eskom's assumptions for the PBMR

Eskom has published few details of the assumptions that underlie its economic case for the PBMR. In 1998, however, David Nicholls (now chief executive officer of the company set up by Eskom to exploit the PBMR) revealed some of the main forecasts on which Eskom’s case was based. The key assumptions were that (a) the construction cost is assumed to be about $1000 (£625) per kW, (b) the plant life is 40 years, (c) the discount rate is 6%, and (d) the assumed load factor* is 95% — it would produce 8300 kWh per year.

The expected running cost was not given, but the fuel cost was estimated to be about 0.4 c/kWh, equal to that of the cheapest U.S. nuclear power plants. Using the American experience of non-fuel operating costs, the total running cost is likely to be about 1 c/kWh (0.6 p/kWh). We are not aware of major changes to these Eskom estimates since that time.

The figures mean that Eskom expects the construction cost per MW of the PBMR to be about 20% of that of the most recent British nuclear power plant. This assumption flies in the face of generally accepted economies of scale, which have led to a continuous upgrading of nuclear plants over the last three decades, from smaller plants producing 200–300 MW to ones rated at more than 1100 MW of power. While the ‘economy of scale’ imperative is losing currency in economic thinking, the nuclear industry still believes that increasing unit size reduces costs. The EPR, for example, a modified PWR design being developed in France by Framatome, was scaled up in 1998 from 1450 MW to 1750 MW to reduce costs.12

More recently, Westinghouse in America has announced that it will scale up its AP600 reactor from 600 MW to 1000 MW to reduce per-kilowatt installed costs.13

(This development contradicts the 1989 justification by a Westinghouse executive at the time the AP600 was being mooted, when he argued for a unit size of 600 MW rather than 1000–1300 MW by saying, ‘the economies of scale are no longer operative’.)

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* Annual load factor is the most commonly used measure of the reliability of a nuclear plant. It is defined as the plant output in a year as a percentage of the output it would have produced had it operated uninterrupted at full power.
Eskom expects the PBMR to achieve greater reliability than any other nuclear plant in the world. Using Eskom’s assumptions about the discount rate and the economic lifetime of the plant this gives a fixed cost of about 0.4 p/kWh. Even if the company’s optimistic forecasts of construction cost and reliability are accepted, and assuming a still very optimistic commercial discount rate of 12% and a lifetime of 20 years, the fixed cost doubles to 0.82 p/kWh. If, instead, discount rates and plant lifetimes now generally accepted in Britain are used (that is, 15% and 15 years) the fixed cost increases to 1.1 p/kWh. Simply by changing the investment appraisal parameters to more appropriate ones, the cost advantage forecast by Eskom for the PBMR over a CCGT disappears.

The PBMR reliability levels projected by Eskom are particularly hard to justify given Eskom’s track record at Koeberg. In 1999, the average load factor for the world’s nuclear power plants was 75%. Over the 16 years that Koeberg has been in service, its two plants averaged a load factor of a little over 60%. In 1997–99, they did rather better, but neither was among the world’s top 50 plants. There is nothing in Eskom’s past history to suggest that it is capable of sustained world-beating performance with nuclear power plants, especially with a new and unproven design.

If a load factor a little above the average of that in plants in the rest of the world (7000 kWh per kW per year) is used as an estimate (rather than Eskom’s 95%), the economics of the proposed plant change greatly. Assuming that Eskom’s estimated construction cost is half of what the actual cost would be (this would still make the PBMR the cheapest nuclear plant in the world to build), and using a 12% discount rate and a 20-year lifetime, the fixed cost alone becomes 2 p/kWh. Using a higher discount rate (15%) and shorter life-time (15 years), the fixed cost changes to 2.5 p/kWh, which is comparable to the full cost (fixed plus operating) of a new gas-fired plant in Britain of about 2.2 p/kWh.

These calculations make it clear that even if South Africa could build PBMRs at less than half the cost per MW that Britain paid for its most recent nuclear power plant; if it could operate them at above the world average level of reliability; and if running costs were as low as they are at the best U.S. plants, gas-fired plants would still be considerably cheaper. Considering the recent discovery of large gas deposits off the southern African coast, this certainly seems to be an option.

The choice of discount rate is critical to the debate about the way national resources are allocated. The total amount of investment capital (public plus private) available to a country for all industrial sectors is limited: if money is spent on low-return projects, funds will not be available to ones with higher returns, and the country’s economic growth suffers. The discount rate applied in Britain is so high because that is the rate of return achievable by investing in comparably risky projects in other sectors of the economy. The more funds that the South African government (which owns Eskom) invests in low-return projects, the more adversely both private and public investment will be affected. Investment in the PBMR may therefore reduce or deny funding to other public sector projects with a much better rate of return — perhaps even within Eskom — such as urban and rural electrification.

It is not publicly known how fully the PBMR has been costed at this stage, and whether or not equipment suppliers have been selected. The history of nuclear power suggests, however, that costs forecast at this stage of plant development do not accurately reflect the costs actually incurred, and estimates must be regarded as no more than indicative. Uncertainty about features that the safety regulator may demand, and the risk that, as design details are developed, additional features or more expensive materials will be required, add to the difficulties. Even after the design has been fully developed, costs cannot be regarded as fixed until a substantial record of reliable operation has been achieved.

For many reasons, therefore, no plant vendor can give a credible cost guarantee. Even a small nuclear power plant such as the PBMR would generate electrical output worth about £20 m per year. Eskom plans to produce these plants in clusters of ten, so a design fault could be repeated ten times over before being discovered. If this resulted in construction delays of just one year, the value of power lost would be £200 m — for which the supplier would be liable. Few companies have the resources to back such a guarantee.

**Costs of regulation and safety**

The HTR’s built-in safety advantages could render another Chernobyl-like catastrophe impossible. These are not sufficient, however, to guarantee overall plant safety. Considerable publicity given in the 1980s in Europe and North America to so-called ‘intrinsically safe’ reactors soon gave way to the recognition that no reactor could legitimately be described as ‘intrinsically safe’; and developers of safety designs now speak of the ‘passive safety’ of plants that rely on natural features rather than engineered systems to protect them in an accident. Eskom, however, continues to describe the PBMR as ‘intrinsically safe’.

Experience with existing nuclear plants and changing historical circumstances will continue to demand new safety requirements. Eskom assumes that the PBMR can be licensed without a containment to prevent the contents of the core being exposed to the environment in a severe accident, for example. It argues that a catastrophic accident to the plant is not plausible. In the light of the terrorist attacks on New York and Washington of 11 September 2001, it now seems unlikely that a new nuclear power plant without a containment would be acceptable. In such a case, the cost of the PBMR will increase significantly.

Despite their safety features, HTR reactors (and the PBMR) contain much highly radioactive material, which means they will inevitably require rigorous and continuing monitoring. This could lead to three categories of unanticipated cost: (a) those arising during pre-construction licensing, (b) those of additional engineering safety barriers specified during construction, and (c) those of requirements imposed by the regulatory regime once the plant has been commissioned. A competent safety regulator cannot approve construction until the full detailed design is available, and the plant cannot get an operating licence until it is built. There is ample experience in Europe and North America of plants, similar in design to those already in operation, running into construction cost and time overruns because detailed design points were deemed inadequate by the regulator. The German THTR-300 plant (the forerunner of the PBMR, with similar passive safety features), for example, ordered in 1970 and commissioned in 1987, had been licensed and was in service for two years before problems at the plant led the regulator to refuse to re-license it without expensive modifications. These high costs were an important factor in the decision by its owners to close the plant.

Britain’s advanced gas-cooled reactor (AGR) is another salutary example. When the Dungeness B plant was ordered in 1965 from a British supplier on fixed cost terms, a prototype plant of this design was already operating successfully. The detailed design proved to contain serious errors, however, resulting in continuous redesigns throughout construction and leading to the bankruptcy of the supplier and two successor companies — whose cost guarantees therefore proved worthless.
units in the first place. The same argument extends to most other countries that might be regarded as potential markets for the PBMR.

The market for the PBMR

The world nuclear power market

Eskom's evaluation of the PBMR prospects is based on projected annual sales of 30 units, at least 20 of which would need to be for export. It is therefore important to establish the world market for nuclear power plants and what share of it South Africa might hope to gain.

In Europe, ten countries have nuclear power plants.

• After national referenda, Austria closed its plant, Italy closed its three plants, and Sweden is committed to closing its plant.
• The German government has decided to phase out nuclear power; the Netherlands and Switzerland look likely to follow suit.
• Spain abandoned work on several unfinished plants in the 1980s.
• In Britain, new nuclear orders are unlikely.
• Finland has recently examined the option of building a new nuclear power plant. The result will not be known for some time; the PBMR was not one of the candidate designs that the potential owners put forward.
• France has invested heavily in developing its own nuclear technology and manufacturing industry and would be reluctant to import plant: it has overcapitalised in the nuclear industry and would not be likely to import nuclear plant.
• India and Pakistan acquired nuclear power programmes. Its two giants, India and China, both have nuclear power plants.

In South America, Argentina has two operating plants and will be reluctant to import any further. Brazil has its own technology, but, after its nuclear power programme was cut, it has been developing its own nuclear technology business there.

In Asia, India and Pakistan acquired nuclear power in the 1960s, but after India exploded a nuclear bomb in 1975 and its international nuclear contacts were cut, it has been developing its own nuclear technology. India exploded a nuclear bomb in 1975, at a final cost of about $9 bn, it is one of the most expensive nuclear plants ever built.

Canada has its own technology, but, with severe problems on the economics and safety side, it has been shutting units down. The electricity industry is being privatized and many existing nuclear plants are being categorized as stranded assets.

• The two Mexican units took more than 20 years to build, with huge cost overruns, so further orders are unlikely.

In South America:

• Argentina has two operating plants and has struggled for more than 20 years to finance the completion of a third plant, of Canadian design.

• Brazil has one operating nuclear plant whose average load factor over a 20-year life has been about 20%. It has just completed a second plant of German design, whose construction began in 1973: at a final cost of about $9 bn, it is one of the most expensive nuclear plants ever built.

Neither of these two countries is likely to place new orders, nor are their neighbours likely to launch new programmes.

In Africa, only South Africa is actively pursuing nuclear power and the chances of nuclear sales outside this country on the rest of the continent are minimal.

Asia seems the most plausible market. Its two giants, India and China, both have nuclear power programmes.

• In North America, all post-1974 orders (of which more than 100 were in the U.S.A.) were cancelled, and new orders are unlikely.

• Although the U.S. utility, Exelon, is a partner in the PBMR venture, strengthening the PBMR's position in America, power markets there are being steadily broken up and Exelon cannot longer invest in new generation plant with any guarantee that its consumers will foot the bill.

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Commentary

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Japan has its own nuclear technologies, but none has been ordered for commercial use. All its operating plants are of U.S. design, and Japanese companies (e.g. Mitsubishi, Hitachi, Toshiba) have for 30 years invested in developing understanding of these technologies and establishing manufacturing facilities for them. Japan has many operating plants (53 at the beginning of 1999), but public opposition and problems in finding sites unaffected by seismic activity make further orders improbable. Established sites have no room for further plants and only two are currently under construction. If Japan orders further plants, they will almost certainly use units of U.S. or new Japanese design.

South Korea has 14 plants in service and another three under construction. It has used U.S. technology and established full manufacturing facilities of its own.

Taiwan has six plants in service and two on order. When these two plants (themselves at risk of cancellation) are completed, the internal market for electricity is likely to be saturated, with little scope for further nuclear plants.

Other Asian countries, such as Thailand and Indonesia, have for 20 years or more discussed the possibility of ordering nuclear plants, but there is little to suggest that these discussions will soon turn into nuclear orders.

Market prospects for the PBMR

The above analysis suggests, in practice, that the world market for nuclear power is small — maybe no more than one or two units a year, or a maximum of about 2000 MW. Eskom would need to sell 20 export units for sustainable production of the PBMR, meaning it would effectively need to dominate this market. It is not clear, however, that a South African designed plant could win any of the available orders, owing to the market’s innate conservatism.

The accidents at Three Mile Island (U.S.A.) and Chernobyl (Ukraine) alerted nuclear buyers to subsequent economic risks. Following a serious accident, all plants throughout the world have to demonstrate that they are not vulnerable to similar events; this can be expensive and time-consuming. If modifications are required, there is comfort in owning a type of plant widely installed elsewhere, whose owners will pool resources to solve problems quickly and efficiently.

The record of rivals to the established PWR and BWR designs is poor, especially in the case of the HTR and the breeder reactor — designs with many theoretical attractions but apparently unable to translate into a working commercial design. Buyers therefore have a strong incentive to stick with tried and tested designs, because buying a new design from a country with no track record in nuclear reactor technology could appear too risky.

A necessary — but not sufficient — condition for sales of a South African-designed nuclear plant on the world market, is a design approved by safety authorities in one or more countries with high technical credibility in nuclear regulation, that is (in practice) the U.S.A. and Germany, and perhaps Japan, the U.K. and France. The possibility of obtaining a safety licence in Germany can be discounted, at least in the medium term, given its policy to phase out nuclear power. France is also unlikely to grant a license request because of its own huge investment in its (PWR-based) nuclear industry, while problems of public acceptance in Japan (given recent accidents such as that at Tokai Mura in 1999) also probably rule out this country. That leaves the U.K. and the U.S.A.

Recent experience in the U.S.A. of licensing new designs sounds a warning. In the late 1980s, a joint utility and government programme was launched to obtain in-principle safety clearance for new nuclear designs. It aimed to remove barriers to the ordering of nuclear plants by providing utilities confidence that the designs they purchased were licensable and would not be subject to unpredictable design changes during construction (even though local licensing criteria would still have to be met).

Seven designs entered the process. Three involved incremental developments of existing designs (advanced light water reactors), of which two were declared licensable. But this experience is not analogous to the process of obtaining safety clearance for a more radical departure from existing commercial designs, as in the case of the PBMR. The remaining four designs submitted represented more significant departures from conventional technology, including the Westinghouse AP600 reactor and the gas turbine modular high temperature reactor (GT-MHTR, General Atomics). Of these, only the AP600 completed the process, in 1998, after nearly a decade of development work, and expenditure estimated at $400 m (R2.7 bn).12 Little progress was made with the GT-MHTR because of the lack of commercial prospects. These experiences suggest that licensing the PBMR in the U.S.A. could be lengthy and expensive.

The AP600 design and one of the more conventional designs that was declared licensable were subsequently sold to British Nuclear Fuels Limited (BNFL), the publicly owned British nuclear fuel cycle company. American taxes were paid out to benefit a company that was sold to British taxpayers. The U.S. utilities that contributed to the cost of this licensing programme will see no return on their investment.

In the U.K., BNFL has an equity share in the PBMR project.13 The company’s considerable financial resources comprise taxpayers’ money, making any commitment to seeking safety clearance in the U.K. subject to public scrutiny: this probably represents considerable risk. Although the issue of new orders for nuclear power plants in Britain has been re-opened, neither BNFL nor British Energy, the privatized U.K. nuclear generation company, has suggested the PBMR as an option. It is doubtful that BNFL would be allowed to invest public money to gain safety clearance for a design of plant with little prospect of being built in the U.K.

Eskom may be planning to sell the reactor into the international electricity generating market as a whole rather than aiming for the nuclear power market alone. If so, we must question the underlying assumption that the PBMR — as a nuclear power source — will be treated by the market like any other source of electricity. The politics surrounding nuclear power have created significant differences of public (and investor) perception between nuclear and non-nuclear sources of electric power, and these perceptions militate against the PBMR’s breaking into the global electric power market. (The cost of the regulatory regime and the inefficiencies of rolling this out over a large number of nuclear plant sites increase further the costs of PBMR electricity generation.)

Even if an international market for the PBMR does emerge — for instance, in China and the U.S.A. — the benefit to South Africa may be limited. In both China and America, prospects for a significant number of sales would lead to pressure to set up local manufacturing facilities for the major high-value items and perhaps also for fuel production. The main nuclear vendors, Framatome and BNFL, could also choose to set up as rival companies to PBMR (Pty) Ltd, jointly offering similar technology and diluting the benefits to the South African economy. (See Box for a summary of Eskom’s partnership arrangements for the PBMR project.)

Conclusion

Despite superficially attractive technical and safety features, the development of the PBMR by Eskom is a high-risk venture, underwritten by taxpayers and electricity consumers in South Africa and
Eskom acquired the PBMR technology under license from a German consortium, HTR GmbH, and set up a wholly-owned subsidiary, PBMR (Pty) Ltd., to develop the design. This arrangement brings technical strength to the project, but reduces the proportion of benefits coming to South Africa. HTR GmbH involved the high temperature reactor capabilities of Siemens (Germany) and ABB (Switzerland/Sweden). Both companies have sold their nuclear divisions, Siemens to the French nuclear vendor, Framatome, and ABB to the British nuclear fuel cycle company, BNFL.

The terms of technology licences are secret, but typically require the licensee to pay a royalty to the licensor on each sale. They can also allow the licensor to specify which markets can be targeted, and give them rights to the licensor’s development work.

On present plans, 65% of the shares would remain in publicly South African ownership. PBMR (Pty) Ltd is fully owned by Eskom, but three potential local partners have options to take shares in the company.

- Eskom would retain 30% of the shares;
- The South African Industrial Development Corporation (a publicly owned organization that provides loan finance to South African entrepreneurs) would have 25%;
- An economic empowerment agency (yet to be identified) would have 10%;
- The two foreign shareholders would be: British’s BNFL, with 22.5% of the shares. (The company has interests in reactor sales, servicing, clean-up and reactor operation as well as its traditional capabilities of fuel cycle and waste disposal services. It is both a supplier of the technology through HTR GmbH and a co-developer. Its expertise in fuel manufacture is likely to be its main technical contribution to the consortium.)
- Exelon, the largest nuclear power plant operator in the U.S.A., with 12.5% of the shares. (Exelon’s promise to buy a large proportion of the first units completed and its commitment to pilot the design through the U.S. regulatory process are its main strategic contributions to the PBMR venture.)

Economically, Eskom’s justification for the PBMR is based on achieving substantial export sales (20 units per year). Examination of the world market for nuclear power shows, however, that few nations are likely to order new nuclear power plants. The poor market prospects for nuclear power are the result of: (a) the unattractive economics of nuclear power; and (b) the pervasive moves to privatize electricity markets, which transfers the risk of building new plants from consumers to shareholders. Those countries that order plants will most likely choose proven options already developed by the world’s leading nuclear power companies.

We conclude that the PBMR project is economically hazardous, gambling public funds on a questionable technology and a faltering market. There is widespread admiration in the nuclear community for Eskom’s development work on the PBMR, but pride in national engineering capabilities and vague geopolitical advantages should not blind government and the public to the risks.


2. The phrase was used by Lewis Strauss, chairman of the U.S. Atomic Energy Commission, at a National Association of Science Writers’ Founders’ Dinner in New York (16 September 1954).

3. The authors have compiled an historical analysis of international experience with HTR technology, which is to be submitted to this journal for publication as a separate communication.


5. It has been reported that Eskom has already contracted the nuclear engineering company Alstom for the ‘design of the PBMR turbine machinery’, see ref. 1.


9. In 1990, as part of a study of the cost of nuclear power for the Nuclear Energy Agency, the French electric utility, EDF, forecast that the cost of a new PWR would be $1093/kW, lower than any of the other 11 countries included in the study; the average for which was $1646/kW OECD Nuclear Energy Agency (1989). Projected costs of generating electricity. p. 70. OECD, Paris.

10. For instance, Harding has argued that the nuclear industry in France is such an important link in the nation’s industrial and economic life, that any major disruptions would have severe social and economic consequences. [See Harding J. (1984). The Ecologist 14, 101–124.]

11. In countries with centrally-planned electricity industries, the real costs of nuclear power might remain obscure, e.g., for lack of adequate information and/or through various means of subsidization.

12. Giant EPR said to be competitive; EDF to decide on order next year. Nucleonics Week, November 5 1999, pp. 1, 15.


15. The load factors are listed in Nucleonics Week, February 10 2000.

16. Large-time load factors are tabulated in Nuclear Engineering International, March 2000.


20. After submission of this paper, the Department of Minerals and Energy established an independent review of the PBMR project and appointed one of the authors (S.T.) to it. The panel’s report is expected in the first half of 2002.