Nuclear energy: current situation and prospects to 2020

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For close to half a century nuclear fission has been providing reliable supplies of electricity to the UK, with virtually no emissions of carbon dioxide. Over that period, the UK nuclear industry has avoided the emission of over one and a half billion tonnes of CO₂. Yet no nuclear plant has been built in the UK for over two decades even though many of the stations in our current fleet are now within a decade or so of the end of their lifetime. Without new plants being ordered soon, the UK’s nuclear capacity will decline dramatically, from 23% today to 3% post-2020—just as considerations of supply security and climate change are becoming increasingly important. Elsewhere in the world, many countries such as China, India, Japan, South Korea, Finland and France are building new stations. Other countries such as the USA, South Africa, and some nations that currently do not have nuclear stations (such as Indonesia and Poland) are making preparations for future nuclear stations.

Globally capacity factors for nuclear plants are higher than they have ever been, averaging around 85% and with the best stations achieving well over 90%. Lifetime can be 60 years. That the economics of such stations compete well with other technologies is well founded and easily verifiable—especially in the face of rising fossil fuel prices and the pricing in of costs for CO₂ emissions—both of which stand to improve the economics of nuclear energy still further. Waste volumes arising from modern plants are just a fraction of those of some earlier stations, and the technologies are in place to deal with them safely and effectively.

Following recent reviews and international developments, there is growing confidence that internationally available competitive designs of nuclear plant will provide part of the solution to the UK’s long-term energy needs.

Keywords: nuclear energy; fission; reactor systems

1. Introduction

Back at the time when the UK Government launched its Energy White Paper in early 2003, four key pillars of energy policy were identified: environmental acceptability; reliability; affordability; and competition in the market. Never stated, but implicit, was a fifth pillar, namely the safety of whatever technologies might be deployed, both to the workforce and to the wider public. The White Paper provided no overt support for nuclear fission, but did recognize the
potential contribution it could make through its low carbon emissions. However, it also noted some issues associated with nuclear energy, in terms of the economics and in terms of waste, both of which, it was felt, needed resolution. As far as the UK nuclear sector was concerned, there was major disappointment with the White Paper which purported to keep the nuclear option open yet neither took nor indicated plans to take practical steps to do so.

The challenges made over the past year to the validity of the policy enshrined in the White Paper, from many respected quarters including learned societies like the British Nuclear Energy Society (BNES), indicated that in its formulation, too much weight was given to short-term issues and too little to the risks attached to the policy in view of the scale of the challenges ahead in delivering the ‘four pillars’. The UK government’s decision to launch another consultation ‘The Energy Review’ in January–April 2006 indicated that policy makers were aware of the emerging major issues with respect to the UK’s commitment to reduce CO₂ emissions. They were equally concerned with security of supply of gas, high oil and gas prices generally and affordability issues arising from the consequences of the UK becoming a net importer sooner than thought, and the emerging generation gap as the UK’s baseload nuclear and coal stations retired over the coming decade. This would lead by approximately 2016 to 80% of the UK’s requirements for electricity being met by burning imported gas.

The fall off in electricity generation contributed by the UK’s nuclear fleet is shown in figure 1. From its peak in the mid-1990s of just over 30%, the capacity attributable to nuclear will drop to just 3% early in the 2020s when the only remaining operating unit will be Sizewell B.

All the Magnox stations are scheduled to retire by 2010, Wylfa being the last one. There is no prospect of life extension for these units, with their lifetime being determined by the life of the Magnox reprocessing operations at Sellafield, scheduled to conclude in 2012.

Figure 1. Timetable of UK reactor shutdowns.
The Magnox reactor retirements are due to be followed soon after by those of the advanced gas cooled reactors (AGRs) of British Energy, although Dungeness B has just been granted a 10 year life extension, being the least ‘worked’ unit in the fleet and BE will wish to explore life extensions for its other units.

As far as Sizewell B—a Westinghouse-designed pressurized water reactor (PWR)—is concerned, there is no reason why it should not benefit from life extension to 60 years, beyond its original design life of 40 years, in line with accepted international norms for similar designs.

Set against the more recent projections, the decline in the UK’s nuclear capacity if not reversed, will have a major negative impact on overall supply and carbon emissions from the electricity sector particularly as electricity demand is growing at around 1–2% annually; carbon emissions have risen in each of the past 2 years, despite the need to put the UK on track for making substantial cuts; UK geography means that we have limited connections with other nations, hence opportunities to import fuel supplies or power in times of shortage are limited. Risks to the UK’s procurement strategy for gas and those of other European countries were highlighted in the recent stand-off between Russia and the Ukraine over the supply of gas and in comments made by Gazprom.

2. Challenges to the cost and waste perceptions

Nuclear generating costs are dominated by the cost of capital and its financing as illustrated by figure 2 for one of the new generations of nuclear power plants offered competitively on the global stage.

The situation for the AP1000 is indicative of any modern light water reactor (LWR) technology. Many studies carried out worldwide indicate the cost per kilowatt installed (or ‘overnight capital cost’) lies within a consistent band. Currently, competitive advanced systems can be delivered for US$2000/kW. This yields a generating cost of 3p/kWh at 8%, but 4p/kWh at 15% rate of return on investment.
Recent studies into the relative economics of nuclear and other alternatives have shown nuclear to be very competitive. One such international study from OECD\textsuperscript{1} is summarized in figure 3. It shows that nuclear is extremely competitive with other generation options.

One point which is very important to note with respect to nuclear generating costs is the relative insensitivity to the price of the raw fuel. Costs of the raw material (uranium) only account for around 5\% of the total generating cost and the overall fuel contribution (allowing for enrichment and fuel fabrication) is typically around 15–20\% (figure 4).

\textsuperscript{1} Projected Costs of Generating Electricity; OECD / NEA / IEA; 2005.

\textit{Phil. Trans. R. Soc. A} (2007)
Regarding time-scales for introducing new nuclear stations, international experience with standard designs (France, Japan, Korea, China) indicates typical construction times of 5 years for the first unit with time-scales for subsequent units in a series of the same design being 36–48 months depending on the design, local circumstances and whether built in pairs or as single units.

As shown in figure 5, one important factor to take into account for nuclear generation compared with other forms in the UK is that nuclear has a unique hurdle to overcome prior to implementation being possible. Notwithstanding approvals through the ‘normal’ planning process of approximately 2 years which would apply to large-scale deployment of any generation technology, nuclear technology has to undergo regulatory assessment, or licensing, of the design for utilization in the UK. This process would typically take 3 years (assuming that the design being assessed has already been approved elsewhere in the world). Thus, even in the most optimistic circumstances, if a decision to proceed were taken now, it would be 2015 before electricity would be delivered to the grid. This means that preparatory steps such as licensing need to be taken now. This does not in any way imply a commitment to build new nuclear plants, but it does ensure that the timeline illustrated in figure 5 could be achievable and that new plants could be built on a time-scale to match closure of some of the retiring stations. This process is relatively low cost (around £10 million) but would have the added benefit of ensuring skills and capabilities within the UK’s nuclear regulatory body were up to date with international best practice.

With hindsight, UK past experience contains a number of case studies in how nuclear projects should not be delivered. International norms over the past 10–15 years are a much better guide and give confidence to any figures and time-scales quoted.

The UK (for what appeared to be very good reasons at the time) chose to concentrate on the gas cooled Magnox system. All the 11 reactors built were different. There was almost no benefit in learning from experience or series build. Different consortia were used to design and construct the different units. A similar path was followed for the AGRs where again there the temptation to ‘improve’ the design after each round of building proved to be irresistible.

Historical cost overruns for both systems can be attributed inter alia to

— ‘design as you go’ approach,
— delays in approvals processes,
— ‘preference engineering’ (the regulators asking for systems to be made similar to what they were familiar with, rather than simply assessing whether a system met the safety criteria or not),
— little prospect of modularization of major components and a very high degree of on site build,
— a ‘cost plus’ culture in regulated markets, which drove suppliers towards overruns and overspends, and
— changing political/legislative/regulatory requirements.

This contrasts heavily with international best practice which is to adopt a proven international design, to resist the temptation to make it ‘better’ and to build a number of identical units as a series.

Both the Magnox and the AGR systems have, however, in general worked well, with good safety records, delivering reliable carbon-free baseload electricity for the UK. In addition, Sizewell B which turned into a one-off imported design with significant redesign during the licensing approval was completed within budget and schedule.

Now, however, there is an increasing body of international evidence to give confidence that construction and operating costs for future nuclear plant are predictable. This includes the following.

— In countries such as France, China, Japan and South Korea, the nuclear industry has demonstrated a good track record of delivering modern designs on time and within budget.
— Nuclear plants around the world show very good operational performance. (There has been significant improvement in nuclear plant reliability over the past 10–15 years, with typical load factors in the 80–90% range. Sizewell B, which is the nearest equivalent UK plant, has delivered similar levels of reliability over its first 10 years of operation.)
— Consolidation of nuclear reactor vendors through the 1990s has led to the development of ‘standardized’ internationally recognized advanced designs. As these designs incorporate many years of construction and operating experience, use proven technology, and robustly address the regulatory issues that were previously of concern, there is much more confidence in construction times and operational performance than hitherto.
— Development of improved materials for construction, and better operational management, allow more reliable operation at high levels of output.
— Reactors are now designed for improved maintainability which reduces operating costs and increases overall output.
— Modern reactors make very efficient use of the fuel, and so produce much less waste than earlier designs.
— Modern designs incorporate fewer components than older reactor concepts which, together with modern construction techniques such as modular construction, makes today’s plants more straightforward to build.
— Modern reactors are designed for safe, cost-effective decommissioning.

When it comes to issues of waste, future waste management costs are a very different consideration from the costs of dealing with the historic legacy which was in the main generated under a very different nuclear industry and energy
The existing UK legacy should not be used to deny future generations the benefits of reliable carbon-free baseload electricity from new nuclear power plant.

The Magnox system is very fuel intensive. This, together with the extensive prototypical radiochemical plants constructed at Sellafield and Dounreay in the period from the late 1940s to the early 1980s in support of a reprocessing and fast reactor fuel cycle, is largely responsible for the UK extensive legacy waste and its high cost. Figure 6 shows the differences between wastes arising from a modern LWR like the AP1000 compared with a Magnox unit of equivalent output.

In general, it is vital to put potential waste arising from new build into context both in the terms of volume and in the difficulty of dealing with it compared with the existing inventory.

If 10 new reactors were built to replace the UK’s retired and retiring fleet of 11 Magnox and 7 AGR stations, less than 10% would be added to the existing inventory of high and intermediate level waste. Less than 3% would be added to the low-level waste inventory. Furthermore, the type of waste produced by modern reactors is much easier to deal with and there are internationally accepted, well-engineered norms for its containment, handling and storage. The reactors themselves are also much easier to decommission, having been designed with this in mind.

With or without any further reactors, the UK will need a long-term management route to be identified for the baseline high- and intermediate level waste inventory. The Committee on Radioactive Waste Management (CoRWM) recommended the long-term management route(s) for UK waste and spent fuel to the UK Government in July 2006 with conclusions and recommendations accepted by the Government in the autumn.

In terms of scale, investment in new nuclear plant is not unique in the energy infrastructure sector. Gas pipelines and oil platforms and LNG facilities can actually cost more depending on the installation and location.

Financial institution appetite and requirement for rate of return is therefore highly dependent on the perceived risks. Where there are unresolved policy, planning and regulatory issues, as is the case in the UK currently, then it is difficult to begin to argue the case for progressing any investment at all. If
however, as for example in Finland, parliament has decided as a matter of policy that a country will have nuclear in its forward energy mix, an international design has been chosen and has regulatory approval, a price has been agreed, the public have volunteered to host the reactor in their community, waste policy has been determined and the liabilities for the utility are clear, financing can and has been secured from commercial sources.

If waste policy is clear and the utilities’ obligations determined at the outset; if a design has generic approval; if the planning process is well defined and appropriately streamlined, then risk becomes easier to assess and accept.

For nuclear energy in the UK, clarity in waste policy is essential as it is currently a significant deterrent (without a statement of policy the owner’s liability is potentially uncapped). Recognition of the fact that nuclear is carbon-free would have a further significant impact if due credit were given.

Let us now consider what technology we have available to us today in the UK if we were to move forward with nuclear. There are many options around globally at the moment. Interestingly, none of them have their genesis in the UK, unlike the systems that we currently operate which, with the exception of Sizewell B, are ‘home-grown’ designs.

The most likely options for the UK, were new nuclear to go ahead, are the European pressurized water reactor which is a Franco-German product, and the Westinghouse AP1000 which is an American product. The EPR design has already been selected in two countries—in Finland, where it is already under construction, and in France. The AP1000 is the lead candidate in the USA for delivery. Both products were in head-to-head competition for the four units to be ordered by China. Westinghouse was announced as the preferred bidder on the

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<th>reactor design</th>
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Table 1. Nuclear reactor technology currently under construction or consideration worldwide.
grounds of technology in December 2006. Longer shots would be the GE ESBWR or the AECL Candu ACR system (table 1).

The EPR design is an improvement on the existing systems operating in Europe, with many safety features added and enhanced protection against aircraft and earthquakes. These were driven by the requirements of the European Utilities Requirements in the mid-1990s. It has some impressive technological advantages, but nevertheless is still considered proven, because it is actually based on existing technology (the N4 design) that is operating in France today and the Konvoi reactors in Germany.

Figure 7 shows an impression of what the EPR will look like once complete in Finland, alongside the existing plants on the same site. The new reactor is due to be delivering power within 5 years. The French demonstrator of the same technology will follow soon after, with the expectation of a further fleet to follow in France.

The AP1000 is the American competing product, again designed to meet the energy markets of the twenty-first century. Currently, 10 units are under consideration by utilities in the USA as part of the administration’s NP2010 initiative to kick-start reinvestment in nuclear energy. The technology is based on passive systems—with a lot of simplicity in the design, which is a key to the economic benefit. Like the EPR, the AP1000 uses proven components already in operation. Key components such as the plant’s steam generators, the pressure vessel and the pumps are already in operation in different reactors worldwide. The Westinghouse AP1000 has been chosen by China in a competition with the European EPR.

On the economics, one might well ask how confident can the industry be that they really will be competitive: we know how many components and how much material in terms of concrete, pumps, valves, and so forth, went into Sizewell B. In addition, in comparison, we know how many of the same items will go into a new design such as an EPR or AP1000. The difference, shown here for the AP1000, is striking—largely due to the passive safety systems, and associated simpler design, mentioned earlier. It is easy to see that the parts list is much shorter; hence, there is a very high degree of confidence in the plant being markedly cheaper than a conventional design (figure 8).
As well as benefits arising from the actual design philosophy of the reactor, there are improvements to be anticipated from the way construction is approached in modern nuclear reactor systems. Whichever design might be selected, an increasing proportion of the construction nowadays takes place remote from the reactor site itself, with sub-modules of the building being fabricated in factories and then shipped whole to the site for assembly. In this way, a large number of construction activities can be carried out in parallel and the on-site construction work is kept to a minimum. Quality control is also often easier in a factory setting than on the construction site. Studies undertaken by the Nuclear Industry Association earlier this year indicate significant opportunities for UK companies to play major roles in the supply of a fleet of nuclear power stations in the UK with approximately 80% components, other than the major vessels, contenders for UK supply.

To summarize, here in UK, we have the chance to select from internationally available, standardized systems that are being built or considered elsewhere. In doing so, we can have confidence that we can expect the same economic and environmental benefits that have driven countries such as Finland to make a pro-nuclear choice for their energy mix. We can expect reliable operation over 60 years at 90% capacity factor and maybe even more. We can expect them to generate base load carbon-free electricity reliably. The generation gap resulting partly from the closure of older nuclear stations will open up significantly over the next 10 years, even if new build were to be started now. In order to secure a reliable and balanced mix in the medium term, decisions to progress new nuclear build must be made soon. In this way, it is possible that three to four new units could actually be supplying power to the grid by 2020. Work on pre-licensing of established international designs should begin as soon as possible. This will help to maintain key skills and will cut the lead time for delivery of any new nuclear plant, without in any way implying a commitment to build. The current lack of a formal waste policy should not be seen as an obstacle to taking steps immediately to encourage nuclear build. There is a process in place to deliver such a policy and the solution will be the same irrespective of whether or not new build takes place.

Figure 8. Components in the AP1000 compared with a conventional design.