BRIEFING PAPER

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Double or Quits? The Global Future of Civil Nuclear Energy

Peter Beck and Malcolm Grimston

Among the many disputes in the field of energy, in many countries none appear to be as acrimonious as those surrounding nuclear power. Its supporters are confident that nuclear power will have an important long-term future on the global energy scene, while its critics are equally confident that its days are numbered and that it was only developed to provide a political fig-leaf for a nuclear weapons programme. Both sides believe the other to be thoroughly biased or stupid and there is little constructive debate between them. As the disputes rage, especially over such issues as the management of nuclear waste, the economics and safety of nuclear power compared with other sources of electricity, the possible links with nuclear weapons and the attitude of the public towards the industry, decision-making is either paralysed or dominated by those who shout loudest. As a result, governments, industry and the financial sector have in recent years found it increasingly difficult to develop policy in this field.

Deciding about future energy developments requires balanced and trustworthy information about issues such as the relative environmental effects of different options, the safety of installations, economics and the availability of resources. This is of particular importance now because world energy use is expected to continue to grow significantly during this century, particularly in less developed countries. In the same period, global emissions of greenhouse gases, especially carbon dioxide, will have to be severely curbed. To meet both these requirements may well involve a step change away from being able to meet growing energy needs by depending on an ever-increasing supply of carboniferous fossil fuel.

To address this situation, the Royal Institute of International Affairs undertook a two-year research project, aimed at providing information from the standpoint of an organization with no vested interest in either the pro or the anti camp, but close connections to both. The project has aimed to illuminate the differences, rather than to adjudicate among the various 'sides'.

The question at issue is what role nuclear energy might play in this new world. It could be expanded rapidly and it clearly has the potential to contribute to mitigating climate change. However, as indicated above, the industry presents a number of challenges.

The project was organized in two parts. The first phase concentrated on the identification of the main issues influencing the future of nuclear energy, and the results were published in December 2000 as an RIIA Special Paper, *Civil Nuclear Energy: Fuel of the Future or Relic of the Past?* This led to the identification of five main issues:

- public perceptions and the process of decision-making;
- relative economics;
- waste management, reprocessing and proliferation;
- nuclear safety;
- nuclear R. & D.

The second phase involved more considered studies of these issues. Following widespread consultation with experts from a number of counties and from both sides of the nuclear divide, Position Papers on each subject were produced. The findings will be published in *Double or Quits? The Global Future of Civil Nuclear Energy* (RIIA/Earthscan, forthcoming summer 2002). The book seeks to clarify the major disputes in this field and promulgate the findings of the project in a form enabling decision-makers and their advisers, within both governments and the nuclear industry, to identify actions that will allow different nuclear options to be kept open – from exit, as has been effected in Italy, to major expansion, as planned for countries in South and East Asia.

This preview provides a flavour of the main results of the project, but it must be pointed out that such results are strongly dependent on the many assumptions used in an analysis. There are few facts but much speculation about the future. To judge the credibility of these results needs knowledge of the main assumptions leading to the results and often even their source. Enthusiasts for wind-power and nuclear enthusiasts will naturally see nuclear power in different lights; both parties will tend to make their assumptions accordingly. As Shakespeare put it, 'the wish is father to the thought'.

An important purpose of the book is to show this interconnection between assumption and result, which cannot usefully be done in a brief note. This preview, therefore, concentrates on reporting results only, though with one major exception – namely, the future of global energy. Unless a view about this subject is taken and the main assumptions identified, a discussion about the future of nuclear energy is worthless.

The energy challenge

As already mentioned, the global energy system has to meet two challenges during the first half of this century.

- First, it has to meet the increasing demand arising from the growing world population and the increasing standard of living of non-OECD countries. Even though the energy demand of the OECD bloc may remain relatively stable, most estimates assume that total energy demand may well double or even treble by mid-century. Some who disagree with such estimates argue that there is considerable scope for the improvement of energy efficiency and that, with proper effort, global energy use can be contained at or around current levels. This may be possible in principle, but past experience calls for caution. If one assumes that a failure to fulfil demand for energy services would be highly destabilizing for the world, it is surely best, at least for now, to plan for a major energy increase in energy demand and consider how this might be met.

- Secondly, there is the issue of global climate change and the growing consensus among scientists about the urgent need to reduce emissions of greenhouse gases and especially carbon dioxide derived from burning fossil fuels. Although it cannot yet be proved that human activity can effect major climate change, there is strong enough evidence for climatologists to suggest that, on the basis of the 'precautionary principle',* carbon dioxide concentration in the atmosphere should be stabilized by mid-century to no more than twice that of the pre-industrial level. This may require a 60 per cent fall in carbon dioxide emissions from the 1990 levels, but might restrict climate change to manageable proportions, although there could well be significant environmental consequences in some areas.

Fossil fuels currently supply some 90 per cent of commercially sold primary energy. This proportion may have to fall to below 30 per cent to achieve the above greenhouse gas limitations in a world using twice as much energy as today. This is a highly challenging, but not impossible, target.

There appear to be four major options for achieving the necessary reductions in greenhouse emissions:

1) reduce the demand for energy, perhaps by improving energy efficiency or increasing its price;
2) make substantially greater use of renewable energies;
3) increase the use of nuclear power;
4) sequester and dispose of carbon dioxide produced from burning fossil fuels.

All these options have one factor in common – their effects are highly uncertain and subject to considerable debate.

* Defined as: 'Where there is uncertainty, assume a pessimistic case for planning purposes'

1) *Energy demand reduction* Improvements in energy efficiency have been a constant feature since the start of the industrial revolution and there are plenty of opportunities for this trend to continue. However, experience has also shown that progress tends to be slower than technological developments might warrant unless governments force the pace (as in the 1970s), a decision carrying with it political risks. Furthermore, it is debatable how far improvements in energy efficiency result in a reduction in energy use. Improvement in efficiency has the effect of reducing the cost of providing energy services and thus releasing resources for use elsewhere. Some of these resources will be used in ways that require energy (say warmer bedrooms, or buying more goods or services which need energy in their provision), thereby reducing the net savings of energy achieved.

The scale of these 'rebound effects' is subject to much debate. It may well be rather small for countries with a high living standard, but larger in less developed countries. Bearing in mind that most of the additional energy needed during this century will be for the latter category of countries, the net amount of energy savings achieved from improvements in energy efficiency is unknown and probably unknowable. However, a major effort to achieve improvements is certainly worthwhile. Even if it did not greatly reduce overall energy demand, it would contribute to increased rates of economic growth and would, therefore, be highly beneficial, especially for poorer countries. It would also increase the amount of energy services provided from fossil fuels per unit of greenhouse gas emissions. If energy efficiency improvements were offset by higher energy prices, of course, the effect on reduced energy demand would be greater, but for the present this runs counter to the policy of energy price reductions in most countries.

2) *Renewable energy sources* In general, renewables do not emit greenhouse gases, nor do they produce significant quantities of hazardous waste. At present the costs of many renewable options are rather high, but protagonists of renewable energy suggest that as experience with the many ways of harnessing these sources of energy increases and as mass production is introduced, so costs will tumble. They believe that, with adequate backing by governments, renewables could meet most of the world's energy demand by the second half of this century.

Others strongly disagree with this point of view. Although the total amount of energy available is vast, the power density (W/m^2) is low (with the possible exception of geothermal energy), and much of the output (wind, direct solar energy) is intermittent and sometimes unpredictable. This has led some commentators to argue that it will be difficult to integrate renewables into electricity supply systems if they are to provide more than 20–30 per cent of total power use. While accepting that renewables must have an important role in the future, they liken the present state of euphoria in some quarters about the future of renewables to the claims of some nuclear enthusiasts in the 1950s, who predicted it would be 'too cheap to meter'.

Here again, is a situation where experts disagree sharply and we have insufficient experience with large-scale installation of renewables to judge who is more likely to be right. As the nuclear industry found, 'the devil is in the detail'. If adequate effort is put into the development of renewables, especially experimentation with their large-scale use, and into technologies for storing of electricity, we may be in a better position to judge how much to expect from renewable sources by mid-century.

3) *Sequestration of carbon dioxide* This might make it possible to continue utilizing more fossil fuel without causing unacceptable increases in atmospheric concentrations of carbon dioxide. The success of the technique requires that carbon dioxide arising from the burning of fossil fuels could be separated from power station flue gases and disposed of so that it would not leak out into the atmosphere. Possibilities include injection into the ocean, aquifers, depleted gas or oil fields or coal deposits, or even storage as solid carbonate.

There is considerable experience of sequestering carbon dioxide in oilfields, but not of the other possibilities. With currently available technology, the capture of carbon dioxide from flue gases and its disposal would be expensive, though if fossil fuels were available at sufficiently low prices and technological advances reduced the costs of sequestration, the technique might look more attractive. Some commentators also fear that carbon dioxide could escape from its store, with damaging implications for health and for climate change. Yet again, then, there is today insufficient information to judge how far new sequestration technologies would make it possible to make greater use of fossil fuels without increasing the carbon dioxide content of the atmosphere by unacceptable amounts. Pilot-scale and commercial-scale plants will have to be constructed before adequate judgment about the potential of sequestration can be made.

4) *Nuclear energy* This is the only non-carbon source for which considerable experience already exists as it presently generates some 7.5 per cent of the world's commercially sold primary energy. In principle it could be expanded to take over from fossil fuels, at least for power generation, but its current problems and the state of public opinion in many countries make it an unlikely candidate for major expansion. It is, however, possible that nuclear technology could evolve in such a way as to make it more acceptable. How this might be achieved is

discussed in the rest of this paper.

The above options are often seen as competitors, although, bearing in mind the challenges of the future energy situation, it may be more likely that contributions from all four will be needed. Phasing out nuclear energy would limit the world's energy flexibility, at a time when most commentators agree that we have insufficient information about the practical potential of the other three options and about future demands for energy. The only rational approach to uncertainty is to keep open as many options as possible to cater for a wide range of alternative futures. This implies that the nuclear option should be kept open, at least for the next decade or so, until more is known about the other options. This is the basic assumption made in our study, which considers whether the nuclear option can be made sufficiently realistic to be plausible.

Public perceptions and decision-making in civil nuclear energy

During the last decade or so, the traditional approach to taking decisions about major projects, whether about nuclear plants or airports, has broken down in many democracies. The approach consisted of industry and/or government developing a project in secret with little or no public discussion; this was followed by an announcement of the result of these deliberations and a programme of 'selling' the decision to the public. This approach has run into more and more trouble in many countries, as decisions taken in secret which do not reflect the views of a wide range of the public have increasingly been rejected at the planning stage, or because of political lobbying or direct action.

There is little evidence that populations at large in most developed countries are of a committed anti-nuclear viewpoint. Despite the heated and acrimonious nature of the debate among those who devote their time to such issues, most observers and stakeholders seem to take a more balanced view or no view at all.

It does seem, however, that politicians in a number of countries mistake the heat of the debate for major public disquiet. Polling of politicians in countries such as the UK and USA shows that they tend to overestimate public opposition by a large margin. Futhermore, public concerns come very much to the fore when specific proposals to build nuclear facilities are made.

Opposition to nuclear power may be ascribed to a number of factors, including:

- disillusionment owing to exaggerated claims on behalf of technology and mistrust of the use of science (especially science sponsored by commercial concerns) in policy-making;
- a perception of arrogance in the nuclear industry, especially in its early days;
- a decline in 'deference' towards politicians and scientists by the public;
- well-managed campaigns against nuclear power, especially from pressure groups and the media;
- the particular nature of nuclear risks – unfamiliar, involuntary and potentially affecting many people, including future generations;
- the major accidents at Three Mile Island and Chernobyl;
- the impression that there are adequate energy resources available, and that nuclear power may not be needed;
- the failure of governments and the industry to develop permanent waste disposal facilities;
- with a few possible exceptions, such as France and Sweden, disappointing experience during the 1980s when bringing nuclear facilities into operation, including over-expenditure, delays and low availability.

Public opinion in a number of developing countries may be more favourable. Their electricity demand is growing more rapidly, and less affluent local communities often welcome the major employment opportunities represented by large nuclear construction projects. However, it is possible that the same forces that have affected public opinion in parts of the developed world may in due course come to bear in the developing world.

With the traditional approach no longer working, several new decision-making approaches are being tested in different countries. They share a number of features:

- far greater openness in the process of consultation;
- involvement of a wider range of parties – existing stakeholders, potential future stakeholders and members of the wider public – in the decision-making process;
- involvement of these parties at an earlier stage of policy formulation;
- greater transparency about the purpose of and reasons for proposals;
- a greater say among possible host communities as to whether, and how, they wish to be involved in discussions.

All aim to improve the quality of the final decisions, and to increase confidence in those decisions by fostering a sense of trust among the stakeholders, a belief that they have a role in the decision-making process and a wider sense of 'ownership' of the decisions.

Many of the innovative approaches are still being evaluated. Although early experience does seem quite promising, especially in Sweden and Finland, there are major concerns how long such procedures might take. Development of new procedures, which could be put into practice without causing unmanageable delay, appears to be a prerequisite for moving forward; more experimentation seems necessary.

Nonetheless, there are potential dangers. Progress on complex issues such as nuclear power, which have scientific, technological, economic, environmental, ethical and social implications, seem to require one of two conditions: either consensus or political leadership, the latter implying a preparedness on the part of the political establishment to take decisions which will inevitably lead to discontent among some groups in society.

These conditions are not mutually exclusive. The greater the degree of consensus, the less the need for political leadership. However, full consensus will never emerge over many complex and contentious issues.

Let us take radioactive waste management as an example. If a workable way forward were to be found, then nuclear power would look more attractive to the general public. It is clear, however, that, for some groups, opposition to nuclear power is an absolute. For these groups it will always appear against their interest to support any measures which might represent a publicly acceptable way forward on waste management, whatever its technical merits. Political leadership will, under such circumstances, be essential.

Whatever difficulties the new approaches to democratic decision-making may present, they offer a number of advantages over traditional methods. However, if the attempt to build complete consensus is interpreted as an alternative to political leadership, then the result could be continuing ducking of decision-taking until the mythical day arrives when all dispute will have subsided. Once a proper degree of involvement of the public has been undertaken, someone somewhere will still have to take that decision. In a democracy, it is difficult to see who the final decision-maker should be if not an elected representative of society at large.

The relative economics of nuclear power

Over 80 per cent of nuclear plants now operating were planned more than twenty years ago and they are mostly light water reactors (LWRs). The decisions to build these plants were largely based on expections that they would occupy a competitive position in the power market, since oil prices (and therefore energy prices in general) were expected to rise. There were also concerns over security of energy supplies in many countries. Furthermore, electricity systems tended to be organized along monopoly lines, in which generating companies had secure markets for their output. These factors combined to create the perception that investment in power generation (including nuclear stations) has a low risk and investors expected no more than ‘utility rates of return’, say around 5 or 6 per cent.

Reality has turned out rather differently, and the economics of nuclear power in many countries appear disappointing when compared to those early assumptions.

- The development during the 1980s of new gas-fired power technology, the combined cycle gas turbine (CCGT), the discovery of large new gas fields worldwide and the era of low fossil fuel prices made gas the main competitor for new plant in countries with access to competitively priced gas in the 1990s. Capital costs for CCGTs range between $450 and $900 per kW(e), compared with $2,000–2,500 for large-scale nuclear plant using designs of the 1980s. Construction time for CCGTs of 1,000 MW capacity may be two years or less, compared with around seven years for conventional LWRs.

- Many industrialized countries have liberalized their energy industries and brought competition into the electricity market. This has meant that new plants no longer have captive customers for their output, and this in turn increases the risk of any such project. Companies now look for more normal commercial rates of return on such investments, say 10–15 per cent. Because of the high capital costs and long construction times of conventional nuclear plant, these changes have a severe effect on their economics. A change from a 5 per cent return on capital to a return of 10 per cent increases the ‘levelized’ cost of a CCGT plant by 10 per cent, against an increase of 50 per cent for a nuclear plant.

- Another effect of introducing competitive markets is the tendency for companies to reduce their risk by looking for smaller, more flexible plant. Here again, CCGTs have an advantage because their size can be economic down to 200 MW(e), while LWR designs, now in use, have to be well above 1000 MW(e) to deliver reasonable costs.

The above comments refer to new plant. Existing nuclear facilities which run well (as by now the majority do) tend to have the lowest marginal cost of available plants, which means that they can attract custom in a competitive market. Where companies have acquired a nuclear plant at a price well below its initial capital costs, the venture can under present conditions be highly profitable.

However, the shift to competitive markets largely explains why there have been so few new nuclear orders in the developed world over the last ten years or so. Unless there are special conditions such as supportive government policies or limited availability of gas or coal, no one in a competitive market is likely to contemplate construction of a large-scale nuclear reactor based on designs now in operation. That would be the case even if there were no other barriers to nuclear investment, such as public mistrust or the question of disposal of nuclear waste.

The competitive position of nuclear power may improve once a country wishes to ascribe a value to reductions in carbon dioxide emissions or to improved energy security. There could perhaps be little confidence that even a beneficial change would be maintained in the long term, as such policies could easily be changed, say if there were a change in the ruling party, although international climate change treaties might make such changes in policy less easy.

Current designs for large-scale plant may also not be suitable for a number of developing countries, especially if there is no grid to distribute the power. Unless competitive smaller-scale plant becomes available, nuclear power is likely to be at a disadvantage in many developing countries where much of the increasing demand for electricity will be based. (At present developing countries use some 30 per cent of total global electricity production. Estimates indicate that this may grow by mid-century to some 60 per cent of a much bigger total.)

Nuclear engineering companies have, of course, been aware of all these trends and have, over the last decade, developed a number of designs which they believe to be more suited to the changed environment of the electricity market. There are two groups of novel designs.

- First, there are a number of much simplified designs for light water reactors, which are claimed to have lower capital costs and shorter construction times. Examples include the Westinghouse AP600 and AP1000 and System 80+, the European EPR and the Russian VVER 640. There is also a Next Generation CANDU reactor from Canada. It is claimed that all these redesigns should be close to being competitive with CCGT plant. So far, however, no commercial-scale prototypes have been built (although reactors with many of their features have been constructed) and therefore the true benefits of these designs have not been proven.

- Secondly, there are more radical developments in train, namely the use of high temperature gas cooled reactors (HTGRs). A prototype for one, a pebble bed design of modular construction (PBMR), is scheduled for construction in South Africa; the full design is being examined by regulators and the International Atomic Energy Agency (IAEA). Each module would have a capacity of 110 MW(e). Current plans are to start construction in 2003 and commence operation in 2006. Assuming normal teething troubles but eventual successful operation, a commercial design may be ready early in the next decade. It is claimed that such a design should be competitive with CCGT units, even assuming relatively low gas prices. If that is achieved, such a design could well be of great interest to developing countries as well as in highly competitive situations.

All in all, there are a number of designs available which, if proven, could greatly improve the relative economics of nuclear energy. This would seem a necessary, though by itself insufficient condition for nuclear power to have a long-term future, since other major issues, such as public acceptability, waste management, safety and nuclear proliferation would also have to be resolved.

But before even this first hurdle can be overcome, commercial prototypes will have to be built. With few exceptions, private companies are unlikely to have sufficient incentive to become involved in such risky ventures and there may well be a case for governments to create conditions in which such demonstration plants could be built.

Radioactive waste management, reprocessing and proliferation

Waste management

Nuclear waste is often said to be the Achilles' heel of the nuclear industry and it is a commonly expressed view that progress in radioactive waste management is a prerequisite to further nuclear development. There is also a widespread conviction that we have a moral obligation to future generations to create an infrastructure capable of implementing a long-term management strategy for all the nuclear waste and of making financial provision for such implementation. What is rarely appreciated is that most existing radioactive waste has arisen from past military programmes, from research and from early commercial power stations. Volumes of waste arising from future nuclear operations would be far smaller per unit of power produced.

The claims by the nuclear industry that waste management presents no particularly difficult technical issues are hotly disputed by the industry's opponents. Furthermore, the industry, broadly speaking, argues for deep disposal of radioactive wastes, both because such an approach allows the insertion of several barriers of different kinds between the waste and the surface and because it would relieve future generations of the responsibility of managing the material. The industry's opponents argue that the current state of knowledge, both of basic science and of the characterization of particular sites, is insufficient to guarantee that material would not leak from a deep disposal facility before its activity had decayed to acceptable levels. Sometimes it is claimed that it will never be possible in principle to demonstrate the safety of disposal facilities over very long periods of time; opponents therefore argue that a better approach may be to use surface or shallow underground storage where the waste can be monitored and easily retrieved if necessary.

Whatever the relative merits of these claims, the failure in most countries to make progress in establishing permanent waste disposal sites, or even appropriate decision-making procedures, suggests that a period of interim on- or near-surface storage is inevitable. Designing these stores and packaging of the wastes for periods of decades, or even a century or more, seems to offer a degree of flexibility to future decision-makers. It would allow for deep disposal if and when a robust safety case can be demonstrated, but create a suitable environment for storing the wastes in the interim. However, achieving public acceptance of such an approach may require clear evidence that a long-term management route had been identified and that there was the will to implement it. Until such plans exist and are believed, the issue of waste is and will remain a potent weapon in the hands of the anti-nuclear lobbies, who argue that no more waste should be produced until acceptable paths of disposal are available.

Eventually there may be other alternatives to long-term storage. Research into methods of partitioning the waste to separate out the longer-lived components and transmuting these materials into shorter-lived radioisotopes (P&T) is being pursued. Although commercial demonstration of such techniques is some distance away, the possibility is raised of reducing significantly the amount of longer-lived materials requiring disposal. However, there is dispute over what proportion of longer-lived fission products could be transmuted in this way, and the amounts and types of secondary wastes (requiring management) that would arise.

The possibility of developing international waste management facilities is also much discussed. It is unlikely that every country which operates nuclear power plants or research reactors – there being more than sixty such countries – and every country which uses radioactive materials for medical uses (most of the world) should have their own long-term waste storage facilities. Means to manage waste from countries with few nuclear facilities will have to be found. While the pooling of resources and of the choice of the most suitable sites might seem attractive, such a policy could well cause considerable political problems, and would in any case have substantial implications for transportation of radioactive materials. Current regulations for shipment, storage and disposal assume that radiation remains a risk down to zero-dose rates. This assumption has been made on the basis of the ‘precautionary principle’ as scientific evidence about the precise health effects of very low doses of radiation is extremely difficult to obtain. Some commentators argue that low radiation levels are not a health hazard and may even keep the immune system healthy, while other evidence appears to show that low-dose rates may be more dangerous pro rata than higher-dose rates. Clarification of this dispute does not appear to be imminent, but it could have considerable implications for the whole issue of waste management.

Reprocessing

Its supporters argue that the main justification for civil nuclear reprocessing is that it makes recycling of uranium and plutonium possible, so reducing the quantity of fresh uranium required per unit of electricity produced. The case for reprocessing, then, is likely to be affected significantly by perceptions of future levels of nuclear power use and the long-term availability of uranium.

At present less than 10 per cent of the spent fuel from nuclear power plants is reprocessed. Should the world nuclear industry decline, or remain at approximately today’s levels, there are unlikely to be major shortages of uranium for many decades. However, should the nuclear industry expand considerably, questions may arise about the economic and resource case for separating out uranium and plutonium (which account for 97 per cent of spent fuel) for reuse. There may also be questions about the eventual requirements for spent fuel disposal facilities, since, if reprocessing were to be pursued, rather smaller volumes of highly radioactive materials would require disposal.

However, reprocessing has some significant disadvantages. The present Purex process produces considerable volumes of waste. Discharges to the environment from reprocessing plants have historically been much higher than from operating nuclear power stations. Reprocessing also produces highly active liquid waste which is potentially hazardous and difficult to treat. The separation of plutonium represents a potential weapons proliferation risk and the process is also expensive. Although new approaches to reprocessing, such as pyro- and electro-chemical methods, may produce fewer discharges and less waste and avoid the liquid intermediate phase, the other issues would still require resolution.

Owing to the present low price of uranium, it is doubtful whether there is an economic case for more reprocessing and it has to be assumed that proposals for new reprocessing capacity, in Japan and possibly in China and India, stem largely from other considerations such as long-term security of uranium supplies.

Proliferation

Bearing in mind the global spread of nuclear technology with (as already mentioned) some 60 countries having research reactors, it is extremely unlikely that any determined state, or perhaps even sub-state organization, could be prevented from developing at least a uranium-based weapon. The existence of a large world nuclear industry could aid proliferation of weapons, but this industry already exists. Further expansion may somewhat increase the dangers, especially if this implies an increasing amount of fissile material in circulation, but this need not be the case if adequate precautions are put in place. It can also be argued that the danger might increase should the nuclear industry decline, as this would throw up redundant nuclear experts seeking work and income.

This being said, the offer of help in developing peaceful nuclear technology as a bargaining tool to prevent countries diverting materials to military uses has been the basis of the Nuclear Non-Proliferation Treaty (NNPT) for over thirty years. This treaty has been largely successful, although some countries have not become signatories and have developed their own weapons capability, while the weapons states have not disarmed (as they are required to do under the terms of the treaty).

If plutonium remains mixed with highly radioactive fission products, it is in effect immobilized and made extremely difficult to use in weapons manufacture. However, the radioactivity of the fission products decays relatively rapidly, and within a matter of centuries spent fuel might become an attractive source of plutonium. It can therefore be argued that to minimize risks of proliferation, ways should be sought to destroy the plutonium rather than to immobilize it. Methods might include using it for power, either in the form of mixed oxide fuel (MOx) for conventional reactors, or in high temperature gas cooled reactors or fast reactors.

On balance, proliferation remains a risk, whatever the future of nuclear power. The effect of changing the scale of the industry on the size of that risk is unclear, but may not be significant.

Nuclear safety

The safety of nuclear installations, both real and perceived, is a key issue when looking at the future of nuclear energy. The industry claims that its performance has been excellent, arguing that with the exception of the Chernobyl accident, which happened in the absence of an effective safety culture and with a seriously flawed design, there has been no incident causing demonstrable off-site health consequences from reactor sites within the fifty years (and 10,000 cumulative reactor years) since the start of commercial operation. Yet some sections of the public are not convinced and tend to mention concerns about safety as one of the main reasons for suspicion of nuclear technology.

The industry's response to the public's concerns, especially since Chernobyl, has been to expend major effort on ensuring that all personnel on nuclear sites see safety as their prime responsibility, while governments have increased the degree of monitoring of the industry by independent nuclear inspectorates. Through the efforts of the IAEA and the World Association of Nuclear Operators (WANO) there is also a great deal of collaboration between plants. As a result, there is now far greater recognition from management downwards that a major accident is possible unless safety is given priority at all times. (Complacency over safety was an important factor in the Chernobyl accident.) Whether nuclear energy is expanded or phased out, a highly developed safety culture will be vital. That, in turn, implies good morale – a matter of concern if uncertainty, say about the future of a plant, is not handled adequately by management.

Should more reactors be built, there will be a focus on new approaches to safety, for instance through simplification, reducing the size of reactors and making use of more passive safety features.

As regards the effect of liberalization of the electricity market, there is no compelling reason to believe that increasing commercialization will have a detrimental effect on safety; the commercial effects of a large accident would appear too serious to allow corners to be cut. Nonetheless, very long periods of activity without any safety implications can themselves induce complacency or a lack of sharpness. Regulators will have to be available to examine pressures to cut costs and other management procedures. In this connection, there is a feeling in many countries that more resources will need to be dedicated to nuclear inspectorates should a major increase in nuclear generation be envisaged.

Nuclear energy research, development and commercialization

The research dilemma

The introduction of competition into electricity markets has had a considerable effect on nuclear energy research and development. Under the system of controlled monopolies in energy, governments saw it as their task to ensure that electricity was available to all potential users at a 'reasonable' price. As security of supply of oil and gas became doubtful during the 1970s and early 1980s, many countries saw rapid expansion of nuclear power as the obvious alternative. As a result, governments spent large sums on nuclear research so as to ensure that suitable technology was available.

During the 1980s, perceptions about limited fossil fuel supplies changed, and energy began to be seen as just another commodity, which could be supplied by competitive markets. In turn this implied that responsibility for research should be in the hands of energy companies, not governments.

As a result of these factors, government expenditure on energy, including nuclear fission, in member states of the International Energy Agency fell significantly between 1990 and 1999: excluding France and Japan – two countries which did not liberalize their power markets to the same degree and which maintained their research expenditure – the reduction was 80 per cent.

Although private companies may have increased their research expenditure to a degree, most of their resources went towards short-term research to improve the performance and cost structure of existing plants. In this they were successful, as by the mid-1990s distinct improvements were to be seen.

Longer-term, strategic research – finding and developing radically better processes – is not only more risky than short-term research, but the time lag between expenditure and potential income, even if the work is successful, can be twenty years or more. A company in a highly competitive market with shareholder pressure for returns is unlikely to be able to commit major resources to such research unless it has strong backing from government or international organizations. This is especially so when considering the final stage of developing new processes, the construction and operation of a commercial-scale prototype. The costs of such a plant tend to be high and there are likely to be teething troubles. Furthermore, the timing of such a plant is crucial; should one wait until more capacity is needed, or build as soon as a design is ready? If one waits, the design will not be commercial when new capacity is first needed, but if one goes ahead as soon as possible, the return from such an investment may be very low, even if it is a technical success.

Main areas of nuclear research and development

The present low level of demand for new nuclear installations for power production has led to a considerable reappraisal within research establishments about the barriers – real or imagined – to expansion. As discussed earlier, these barriers range from doubtful economics in many countries (relative to the use of natural gas) to public distrust of nuclear power in general. In addition, there is overcapacity in electricity generation in most OECD countries.

In due course this overcapacity will diminish unless new plants are built. Furthermore, a number of industrializing countries, such as China and India, are expecting high growth in electricity demand and believe that nuclear power has an essential role in meeting such demands. Hence the possibility exists that at some point the global case for nuclear power may appear stronger than it does today. This possibility would be increased if nuclear power succeeded in addressing some of its own problems. Research is therefore needed to:

- improve the relative economics of nuclear power;
- improve safety by reducing still further the chance of major accidents, but also ensure that adequate and understandable information is available to the public;
- reduce waste production, especially of long-lived elements, and develop ways of managing the waste that has already been produced;
- improve fuel efficiency (which in turn reduces waste production);
- ensure resistance to weapons proliferation.

In addition to more theoretical research, such as the effect of low-level radiation on the onset of cancer, the programme might involve work on:

- new types of reactors;
- availability of uranium and different fuel cycles;
- new types of reprocessing;
- managing radioactive waste, including P&T as an option for future wastes.

All of these developments will require research, development and, especially, demonstration plants. Already several international projects have been initiated to look at longer-term, more ‘revolutionary’ technologies, as well as evolutionary changes of existing technologies. This has led to several new designs, especially in the field of reactors, which are at or near the point of licensing. However, even if, on paper and in the laboratory, a new reactor design promises lower construction costs and more reliable operation, a potential investor will require hard evidence that these promises can be honoured in practice – and this implies construction of commercial-scale prototypes.

This leads to a sort of impasse. There may be little demand for new nuclear plant, at least in some areas of the developed world, unless a practical design has been demonstrated (though perhaps not even then). But the investment in development and commercialization needed for such demonstration may well not be forthcoming from the private sector unless there is some reasonable prospect of market demand for these new types of plant or processes. This dilemma may also apply to development of large-scale renewables, and of sequestering carbon dioxide.

Who, then, if anyone, should be responsible for providing the resources for constructing demonstration plants, a very high-risk investment? Answers to this question may be of major importance to the future development of nuclear technology. Should this role be left purely to the companies, which in principle stand to make commercial profit from the exploitation of such designs if the scheme is successful in technical terms, or is there a role for state support – either in direct grants, or through other mechanisms such as tax breaks – to aid the demonstration phase?

Such dilemmas are beginning to be recognized. In a global market there may be possibilities for collaboration between companies and governments of several countries to provide a basis for going ahead with commercial-scale prototypes. The South African PBMR project is an example; it involves a South African government-owned company, as well as companies from Germany, USA and UK.

Conclusions

The aim of this project has not been to come to judgments as to what role, if any, nuclear power will or should play in future energy supplies, but rather to expound and develop, from an uncommitted standpoint, the arguments used by proponents and opponents of the technology. Nonetheless, we feel it appropriate to highlight some themes which have emerged:

1) The nuclear option will always remain ‘open’, in the somewhat trivial sense that the technology is understood, and records can be maintained even if no more stations are built and existing ones come off-line. To restart such an industry, though, would be a major and lengthy undertaking, while the uncertainties and the size of the challenges associated with the issue of energy and the environment over the next decades are considerable and can emerge rapidly. It can be argued, then, that actions should be taken now to ensure that nuclear power is available as a practical option.

2) The extent to which such actions should be taken will depend on such factors as perceptions of the size of the energy challenges, the extent to which nuclear technology can evolve and matters of politics and values. However, given the timescales involved, serious consideration must be given to what actions (if any) are required now, and in the near future, if the nuclear option is to be kept meaningfully open for, say, the year 2020.

3) The track record of nuclear energy, so far, is a matter of dispute between supporters and critics of the technology. To its supporters, nuclear power has largely fulfilled its early promise – it now generates about one-sixth of the world's electricity, having been the fastest growing of the major energy sources in proportional terms throughout the 1970s, 1980s and 1990s. It does so safely (it is among the safest of the major energy sources, according to some studies) and without emitting significant quantities of greenhouse gases. To its opponents, nuclear power has not fulfilled its promises – in terms of economics, the failure to find a waste management route, the potential for major accidents and terrorist attacks, and the way the industry has behaved towards society. They believe that a 'second chance' should only be contemplated in the most extreme of circumstances, if at all.

The reality, we suspect, lies between the extremes.

4) As regards the future, the extent to which nuclear power will appear attractive will depend on impressions of two main factors – the 'environment' in which it is operating, and its own intrinsic features. Several elements within this environment are largely outside the control of the nuclear industry itself. In a future of energy shortages, disappointing performance of renewables and acute fears about climate change, for example, nuclear power would presumably look more attractive than in a future of limited energy demand, flourishing renewable industries and perceptions that climate change is manageable.

5) As noted earlier, the nuclear industry itself might be able to take a number of steps to make itself more attractive, for instance by developing smaller and cheaper reactors, but there are potential logjams. Even supposing that acceptable technical solutions, at reasonable cost, can be developed for the major areas of concern, it might nonetheless prove very difficult to reach that state of development. For example:

- companies might not be prepared to put in the research, development and commercialization effort necessary to demonstrate cheaper and safer nuclear designs without a reasonable prospect that such designs will find a market, but such a market may not emerge until the designs are ready.
- development of novel waste management techniques such as partition and transmutation may only make sense if there is an expanding nuclear industry, but such expansion may be impossible without new ways of managing waste.

Similar problems may be encountered with respect to renewables, carbon dioxide sequestration and perhaps even demand-side technologies. In order to ensure that solutions to the major areas of difficulty become feasible, governments – either alone or in international collaboration – may have to act now, or very soon, to ensure that there are ways of clearing these logjams by providing stimuli for progress.

Perhaps the most difficult issue is over the construction of demonstration plants. If private companies should prove unwilling or unable to build such facilities, the financial risk being too great, then, in our view, governments should be prepared to take steps to ensure that such plants are built. Without them much of the longer-term research effort is likely to be wasted.

6) Governments will also have to create the circumstances in which there is a sufficient supply of suitably qualified individuals to staff the industry and the regulatory bodies – this is true whether the industry contracts or expands. Governments may also have to act to ensure that sufficient funds are being put aside to deal with waste management and decommissioning in the long term.

7) Finally, there is the issue of how the industry can make itself more acceptable to the public and how to involve it in the decision-making process. As the industry has lost its favoured position with governments, so it seems to have lost some of its early arrogance. Considerable thought is being given to ensuring that the public is and feels that it is contributing to the decision-making process. This trend must continue if the feeling, still prevalent in some circles, that nuclear power is something imposed upon, rather than a part of society, is to be overcome.

In the immediate future, it looks likely that the 'centre of gravity' of nuclear activity will continue to move away from North America and Western Europe and towards South and East Asia. Before long, however, a new understanding between the people, governments and nuclear industries in the industrialized world may be needed. Such an understanding should open the way for proper international appraisal of whether, and in what circumstances, nuclear energy might make a positive contribution to meeting the energy and environmental challenges that the world has to face in the twenty-first century.

Peter Beck and **Malcolm Grimston** are Associate Fellows with the Sustainable Development Programme at the Royal Institute of International Affairs.

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THE ROYAL INSTITUTE OF INTERNATIONAL AFFAIRS
Chatham House 10 St James's Square London SW1Y 4LE
Tel 020 7957 5700 E-mail contact@riia.org
Fax 020 7957 5710 Website www.riia.org
Charity Registration Number: 208223