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An Enquiry into the Future of Civil Nuclear Energy

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The issue of nuclear power has for some time, at least until relatively recently, been conspicuous by its absence from serious debates about the future of energy and, especially, the global climate. There has been something of a policy paralysis in many (but by no means all) countries. In such countries, no new nuclear power stations have been built, radioactive waste has accumulated, and the body of nuclear expertise and construction capability has dissipated.

This has not been because there are coherent non-nuclear strategies to address future problems of energy supply and greenhouse gas emission reductions. Rather, it is because it appears too difficult to take the decisions on nuclear power which would be necessary to overcome some of its unattractive features (especially its high capital intensity) and allow it to complete more fairly with other sources of energy.

Though there may be many reasons for this, it looks likely that one of them is the polarised nature of the debate, something it shares with other issues such as genetically modified food (with similar consequences). The dramatic differences between the extremists on both sides of the debate might be summarised — perhaps with a mild degree of exaggeration — as in Table 1.

Several possible reasons have been adduced for the particularly vitriolic nature of the civil nuclear debate. They include:

- the perceived link between nuclear power and nuclear weapons;
- the perception of secrecy in decision-making;
- the perception of a culture of cover-up and dishonesty;
- the "imposed" nature of nuclear risks upon many people;
- the fact that radiation is unfamiliar and undetectable;
- the apparent potential for nuclear power to cause damage to vast numbers of people and to future generations, especially through large accidents;
- the perceptual weakness of the link between the activity and the benefit.

Whatever the truth, in the absence of a source of reliable and objective information the temptation to duck decisions in highly controversial fields is a strong one. Yet, with the admirable exceptions of a number of impressive reports from independent institutions such as the Royal Society and the Royal Academy of Engineering in the UK, such information is hard to come by.

Starting Points

World energy use has grown consistently for many decades, and is expected to continue to do so, as populations increase and as poorer countries embrace industrialisation. Much of the projected growth will therefore take place in presently less developed countries. Plentiful energy supplies, and especially

electricity, lie at the basis of modern lifestyles in the developed world. Global emissions of greenhouse gases, especially carbon dioxide, have also grown significantly and, even assuming the success of the Kyoto Protocol, are on an upward trend.

However, beyond a belief that energy demand is likely to continue to grow, there are very few global generalisations to be made. In some countries in the developed world energy use is practically static, while it is increasing at high rates in some developing and newly industrialised countries, more than doubling in South Korea and Thailand through the 1990s. In some developed countries, such as Japan, security of supply is a major driving factor behind energy strategy, while in others, such as the UK, security of supply is not considered problematic in the foreseeable future. Some countries such as Sweden, Norway and the Netherlands have traditionally taken global environmental issues very seriously, while for other countries factors such as providing energy for large populations living in poverty have understandably taken higher priority.

In some developing countries, such as China and India, nuclear power, including reprocessing, is seen as a central component of strategies to provide secure and environmentally acceptable electricity production, while in Germany and Sweden it is planned to phase out nuclear power before the end of the economic lives of the stations, and indeed Italy has already followed this course. In some countries nuclear power appears popular, in others it is not a major public issue, in others still it is a focus of malcontent. In some countries the economics of large plants appears favourable, in others no nuclear construction is presently contemplated by private sector funding institutions.

Matters are further complicated by the enormous timescales involved in energy. From first examination of a new technique to widespread commercial application can be a matter of decades. Expanding the world's gas pipelines, installing significant solar capacity, constructing a large programme of nuclear power stations or wind generators, are all likely to take decades. History suggests that commercial exploitation of new technologies is generally rather slower than is regarded as feasible or desirable by their enthusiasts. In certain circumstances, e.g. the "dash for gas" in the UK in the 1990s, it can proceed rapidly, but only if an appropriate infrastructure is in place.

As the world moves towards the tenth anniversary of the Rio Convention in 2002 it is clear that major policy decisions may well be needed very shortly if climate change, for example, is to be restricted to manageable proportions. Whether or not nuclear power could or should have a role in mitigating climate change, improving security of world energy supplies or reducing energy costs is an open question, but an important one. It is unlikely that abandoning this, or any other technological option, simply because it is too difficult to cut through levels of emotion and vitriol on both sides, would result in the best use of potential resources.

The Nuclear Debate

To embark on a project designed to increase understanding about the areas of dispute between two "sides", insofar as one can characterise such a complex debate in terms of two sides, is to face two challenges.

The first is to assess what various parties believe to be the "facts" about the various topics of importance in the field, such as the requirement for secure energy supplies, the management and destination of radioactive waste, climate change, the relative and absolute safety of different energy sources, nuclear weapons proliferation, the importance of research and development, and others. Many of these areas do not yield "facts" very readily, as they involve making projections of a highly uncertain future, often armed with nothing more persuasive than hope, or extrapolations of a past which is itself open to different interpretations.

For example, much work has been done on projecting world energy demand over the next decades. Even so, very little can be said with any certainty, except perhaps that increases in energy demand can be expected on a global scale. Notwithstanding statements made by nuclear protagonists that nuclear power will be "needed", or by opponents that it will not, one cannot be certain today whether a major nuclear industry, or indeed any nuclear industry, will (or should) be making a contribution to solving global energy and environmental problems, say in fifty years' time. Bearing in mind the differences in energy strategies to be found today, it is highly likely that radically different approaches will be followed in different regions of the world, or even in different countries within the same region, depending on local circumstances and values or traditions.

The second involves a dispute between different value systems, in which the protagonists on each side hold world views which are not amenable to challenge through reference to facts or reality. Indeed, the very same "facts", even when broadly accepted by both sides, can result in very different interpretations. To those in the nuclear industry, for example, Three Mile Island demonstrates how safe nuclear power is — 3000 MW of thermal power went out of control without causing any casualties or significant off-site contamination — while to the anti-nuclear side, Three Mile Island is an icon of the dangers of the technology. To the pro-nuclear, plans to bury nuclear waste several hundreds of metres underground demonstrate how safe the industry is; to the anti-nuclear they demonstrate how dangerous the waste is.

Wherever the same "facts" lead to diametrically opposed conclusions, it is at least possible that their interpretation is being driven by pre-existing attitudes to nuclear power. If this is indeed the case, then reducing the gap between the two sides may be a difficult task indeed. However, it remains important at least to understand the nature of the gap.

With these observations in mind, and following on a more general study of the subject in 1994, the Royal Institute of International Affairs (RIIA) set up an Enquiry into the Future of Nuclear Energy. It consists of two phases.

Phase 1 of the RIIA Project

Phase 1 of the project began in October 1999 and will conclude in September 2000. Its aims have been to define and provide an understanding of the main areas of agreement and dispute within the nuclear field; to identify which of these have been relatively well researched and those which have been relatively neglected; and to propose a programme of research for Phase 2.

A wide range of opinions was received, from different positions on the pro- to anti-nuclear spectrum and from different countries. The results will be published shortly after this Symposium in a position paper, which will seek to present pro- and anti-nuclear views side by side and provide an accompanying commentary. This approach to presenting different views may be unique in the field.

The Main Issues

The project has considered three groups of issues. The first group consists of relevant issues which are largely outside the control of the nuclear industry, but which serve as the "environment" in which the nuclear industry must operate. It includes:

- energy demand and choices;
- climate change;
- health effects of low levels of radiation;
- regulatory issues.

The second group consists of those over which the nuclear industry has a major influence. Such issues include:

- the economic attractiveness of nuclear power;
- nuclear research and development;
- safety of nuclear facilities;
- infrastructure necessary to preserve the nuclear option;
- skills requirements in the case of nuclear phase-out.

The third group consists of issues over which the nuclear industry has some but not complete control. It includes:

- nuclear proliferation;
- public perceptions/politics;
- waste management;
- reprocessing.

Of course, these categories do not have sharply defined edges and their effects can interact. The availability of nuclear power might have an effect on overall energy demand, while the costs of nuclear power will certainly be affected by the stance taken by regulators. Nonetheless, if only as an organisational tool, these categories have been helpful to the authors.

Limitations of space prevent a full catalogue of the findings of the preliminary studies here. However, three areas may serve as examples.

Keeping the Option Open

It is almost a truism to say that the nuclear option should be kept open in case future generations view nuclear expansion as the best option. It is certainly hard to argue that this generation should, or even that this generation could, entirely prevent the people of, say, 2050 undertaking a major nuclear programme.

However, the oft-used phrase "keeping the nuclear option open" is a difficult one to quantify. First, it is not clear what it means. To some, it seems to mean early orders of new nuclear plants in advance of market demand, in order to safeguard the skills necessary for such projects. By definition, this would require considerable action by governments, either in providing the capital for such investment or ensuring the existence of a guaranteed market for the

output of such nuclear stations, probably at guaranteed prices. To others, the nuclear option will never close. The existence of records of nuclear science means that a restart using current technology will always be possible, even if nuclear technology should become moribund for some years.

The question then arises, "open to do what?". For example, the requirements of a nuclear industry of approximately the current size, based largely on replacement of existing capacity or perhaps of slow growth, might be radically different from the requirements of a nuclear industry say ten times the current size.

It may be fruitful to consider three simple scenarios for the future of nuclear power in, say, 2050:

- "Red" — slow withdrawal from nuclear power as existing plants reach the end of their lifetimes in the developed world and as developing countries find alternatives to currently planned nuclear expansion leading to effectively zero capacity in the second half of the 21st century.
- "Amber" — continuation of the present situation, including replacement of existing reactors, some new capacity in developing regions, resulting in modest growth of capacity towards 600 GWe, representing some 2% to 5% of global primary energy demand.
- "Green" — a major expansion to some ten times current capacity in the second half of the century, representing perhaps 15% to 30% of global primary energy demand.

In the Red scenario "keeping the option open" involves no more than preservation of sufficient skills to deal with the legacy of nuclear waste, facilities to be decommissioned, decontamination of land, etc.

In the Amber scenario a continuation of present policy might be sufficient, with new reactor designs being based largely on existing concepts. It is likely that there would be sufficient uranium to sustain such a scenario for some time without a requirement for reprocessing of spent fuel. However, even here it is likely that a considerable amount of preparation, including R&D, would be necessary. Key requirements might include:

- development of a wider range of reactor designs, to include smaller plants with lower capital outlay and shorter construction phases more suited to competitive electricity supply markets and possibly some developing countries, as well as large plants for more centralised systems;
- significant progress on management of waste;
- more sophisticated methods of decision-making that can engage and involve local communities and other interest groups.

To be ready to respond to the Green scenario it is likely that considerable effort would have to be expended in the near future. For example, a major nuclear expansion might require, in addition to likely needs for the Amber scenario, any or all of the following:

- new approaches to reprocessing;
- plutonium powered reactors;
- plutonium producing reactors;
- partition and transmutation as an approach to managing spent fuel;
- methods of extracting uranium from seawater;
- use of thorium.

A considerable research and development effort may be required to ensure that a suite of techniques is available that would allow suitable responses to Red, Amber and Green scenarios.

Public Perceptions and Decision-Making Processes
It seems to be common currency that nuclear power is subject to active antipathy among the general public in many countries. It is less clear why this impression has arisen, however. For example, opinion polling carried out by MORI in the UK in 1999 suggested an interesting relationship between public perceptions, and the perceptions of those perceptions among decision-makers (see Table 2). These data imply that at least in some countries the perception of public opinion among decision-makers may not be accurate, perhaps being driven by the activities of pressure groups and by generally anti-nuclear popular media.

However, generalised public opinions are only one aspect of the issue. Attention is turning more to the attitudes of certain key groups, notably local communities, when nuclear projects are proposed. It is clear that the old "decide–announce–defend" (DAD) model of decision-making has become increasingly discredited in many countries. Building legitimacy and consensus around specific decisions and programmes is increasingly important, at least in some countries.

It is a truism to say that continued operation of the nuclear industry, let alone expansion, will require new facilities to be built as existing plants are closed down. Although current plant economics in countries such as the USA have improved to the extent that lifetime extension is now much advocated, there will come a time when it is no longer economic to refurbish an existing nuclear plant, and new capacity of some kind will have to be ordered.

There has been an increasing trend in some countries, notably Canada, the UK and Germany, for protestors to take part in direct action, sometimes of a violent nature, against specific proposals or facilities in areas such as road building, luxury home development, logging, animal experimentation and nuclear transport. Such actions often extend to individual workers or company directors in an attempt, often successful, to intimidate them into abandoning the plans in question.

Even in the absence of such more extreme actions, local communities have proved themselves increasingly adept at building consensus against unpopular projects, even (or perhaps especially) if these projects have a national or federal dimension. The use of political actions involving local politicians has become more prevalent, often coupled with sophisticated local campaigns which make it difficult for opposing views to be expressed.

Over recent years considerable work has been done in an attempt to develop innovative ways of ensuring more involvement from potentially affected communities and society at large in such decisions. Such work — it is sometimes referred to as a "stakeholder" approach — has included citizens' panels, consensus conferences and stakeholder dialogues, in some cases building on experience of well-established local liaison committees. Ways of using the planning process so that any development would benefit local communities are also being explored.

An adjunct is the necessity for the decision-making process itself on the part of industry and government to become more open, and to involve groups other than the technical experts at an early stage of discussion. The ultimate aim should be to foster "consent", not merely "acceptance", among potentially affected communities. This is an area where more work could prove very fruitful.

The Relative Economics of Nuclear Power

It would seem obvious that, although matters such as public perception and waste management will of be key importance in determining the future of nuclear power, nobody will wish to build nuclear stations unless there is a product which is attractive to decision-makers, particularly in the capital markets.

Energy demand in the developed world is not expected to grow at high rates in the future. Although the share of electricity within the general energy mix is expected to increase, many developed countries have something of an over-capacity of electricity plant at present. Demand for new plant may therefore be modest in the foreseeable future and may be limited largely to replacement capacity.

In the 1970s decision-making about new nuclear stations and other generating plants lay fundamentally with governments, and with government-appointed regulators. Even in some countries in which nuclear stations were in the private sector, such as Japan, governments regarded it as their role to ensure that strategic forms of electricity production were constructed as a hedge against future increases in hydrocarbon fuel prices or interruptions in availability. Governments offered utilities a highly regulated local geographical monopoly, thereby creating a guaranteed long-term market for their output. As a result, they could invest in highly capital intensive forms of electricity production (with the approval of regulators), knowing that the investment could be recouped from captive customers over a long period of time. Especially in the USA, nuclear power was regarded as being the cheapest option available.

The easing of the world hydrocarbon fuel situation through the 1980s (and in particular the discovery of enormous reserves of natural gas), the development of the combined cycle gas turbine (CCGT) with its high thermal efficiency and lower costs, and perhaps the influence of changing political fashion, led both to a reduction in the costs of fossil-fuel generated electricity and to the liberalisation of electricity supply systems in many developed countries.

As a result, the companies competing to generate electricity have become more concerned with short-term returns on capital. Reduction of economic risk has assumed a high priority. Gas-fired capacity has become the preferred option, mainly because of its low capital costs but also because of lower perceived overall ("levelised") costs; longer term sources such as coal and nuclear power have fallen out of favour. Gas, where available, has also faced less public resistance in some countries. No nuclear order placed in the USA since 1977 has been completed, and the building of nuclear stations and the ordering of new nuclear capacity in the European Union has halted, with the possible exception of France.

A further effect of liberalisation has been to promote the attractiveness of smaller generating units, of a few hundred megawatts or smaller, over the 1000 MWe plus units typical of the 1970s. However, some large gas-fired units, requiring relatively low capital outlay, are still being ordered.

Large units face problems both over raising capital, and over matching changing loads in markets increasingly characterised by a large number of small generating units. At present there is no up-to-date proven nuclear power design of capacity below about 500 MWe. Both renewables and small-scale gas turbines, including combined heat and power (CHP) stations, may be better suited to a market in which an increasing fraction of the total load comprises large numbers of small users rather than a relatively small number of large customers such as, in the UK, the former regional electricity boards. As the average unit size falls, so it will become more difficult to manage large units coming on- and off-load, for example for maintenance. The likely growth of small, largely self-contained local grid connections may exacerbate this development.

This being said, it remains an open question as to the extent that baseload will still be required even in liberalised electricity markets; in less liberalised markets baseload is likely to remain very important. Large nuclear units may well remain attractive in countries such as France and Japan as well as in several developing and newly developed countries where electricity demand is growing at a fast rate. Further, liberalisation has brought to bear downward pressures on the costs of operating existing nuclear plants, pressures that tend to be absent or much smaller in centrally controlled economies without competition.

A return to a more centralised model of electricity markets, perhaps because of resurgent fears about global energy security, or because market instruments fail to deliver sufficient reductions in greenhouse gas emissions, or because liberalised markets prove incapable of ensuring security of electricity supply on an hour-by-hour basis, might lead to a renaissance in large plants in other developed countries. Alternatively, liberalisation may proceed further in countries where it is still relatively less advanced. Either of these trends might lead to a narrowing of the gaps between policy in various developed countries. It is however perfectly possible that major differences in nuclear policy between developed countries might persist.

Growing concerns about the environment, and especially about climate change, are leading to a reassessment of energy policy. It seems likely that a variety of market instruments to internalise the economic costs of emissions of pollutants such as carbon dioxide will be introduced, including perhaps pollution taxes (or its less efficient surrogate, energy taxation), tradable emission permits, and schemes whereby investment in pollution-saving devices in other countries can generate credits for companies carrying out such investment (known in the Kyoto Protocol as Joint Implementation and the Clean Development Mechanism).

Certain measures have already been introduced in some countries, e.g. Norway. Such mechanisms would improve the economics of nuclear power and of renewable methods of electricity generation relative to that of the fossil fuels. Pollution taxation might however do little to overcome the inherent economic risk associated with large-scale highly capital intensive projects;

smaller reactor models, some of which are in an advanced state of design, may still be required in some markets.

At present the richest 20% of the world's population use 55% of the world's energy, while the poorest 20% use only 5%. Although it is unlikely that such disparities will disappear rapidly, most of the expected growth in world energy (and especially electricity) demand over the next decades will almost certainly be in countries which are at present relatively undeveloped.

The situation in many developing countries is rather different from that in the developed market economies. In many countries of the Asia-Pacific, for example, demand for energy continues to grow rapidly, but access to plentiful gas reserves is, for the present at least, limited. As a result, several countries, such as China, India and South Korea (as well as Japan), remain publicly committed to the large scale development of nuclear power in the immediate future. Significant energy growth is also expected in Africa and South America, where (with the exceptions of South Africa, Brazil and Argentina) nuclear power is not at present used.

These economies retain a degree of central control, which makes raising capital for large-scale schemes less problematic than in the more market-oriented systems. Further, the rate at which energy (and especially electricity) demand has been growing, for example in China, has made it seem unlikely that any single source of electricity can expand sufficiently rapidly to fulfil this demand.

However, questions remain over the suitability of nuclear power for some developing nations. Capital is often a constraining factor, especially in view of the current unwillingness of many world financial institutions to lend money for nuclear projects. Large capacity plants, such as modern nuclear stations, require a major grid infrastructure to be effective. It is argued that the technical complexities of nuclear science and technology compared to lower-technology fuels would offer challenges to the engineering infrastructure of some developing (and indeed developed) countries, although such countries have proved quite able to handle many complex technologies such as aviation.

Voices within the former Soviet Union also talk of a renaissance in nuclear construction, both the completion of suspended projects, such as Rivne-4 and Khmelnitskiy-2 in the Ukraine, and new plants. However, the situation within the region is a volatile one.

It is possible, then, to envisage one future in which some countries, perhaps those which retain a more regulated electricity supply industry, will continue to develop their nuclear industries, while nuclear power construction in some countries with more market-led electricity supply may be limited to replacement capacity, or perhaps not even to that.

The implications of market liberalisation, the required availability of smaller nuclear plant designs with lower capital costs, and the implications of electricity supply systems dominated by smaller localised generating units, are areas which require further investigation.

Phase 2 of the Project

Phase 2 will involve the production of a series of research or review reports on the major issues. The scope of Phase 2 will depend on the funding available, but it is the intention to consider a small number of central issues in depth rather than a large number superficially. Following discussions, the following issues have been identified as being especially worthy of further research:

- public perceptions and decision-making processes;
- waste management;
- the relative economics of nuclear power;
- keeping the nuclear option open;
- nuclear R&D.

Inevitably, these issues will include elements of each other and of the other issues listed above. However, they will form the focus of the further research in Phase 2. It is intended to clarify the key questions associated with each of these issues, and to ask at least two external agencies from different viewpoints to address these questions. Once again the contrasting views will be presented side by side insofar as this is possible, with a commentary and overview from the authors.

A further key output of Phase 2 will be a programme of promulgating the findings to decision-makers. Much detailed and valuable work has been done in the area of nuclear power, environment and energy, but it is less clear that the results of such work have reached decision-makers and their advisors. This will be pursued by contributions to conferences, meetings and discussions.

Conclusions

Despite the assumptions of many, the future is an unknowable region. The key for the present generation must be to ensure sufficient flexibility is available to future generations so that they can respond to whatever circumstances in which they find themselves. It is easy to envisage futures in which nuclear power will not be "needed" and others in which it will — or to be more precise, futures in which nuclear power will be a net problem or a net benefit.

The present diversity in attitudes to nuclear power in different regions may persist or even widen. We must plan towards as many of these possible futures as possible. The long timescales involved in energy supply mean that decisions taken — or not taken — today will have implications several decades into the future.

This means that the nuclear option should in some sense remain open. That in turn means that it must be acceptable to the public and to decision-makers; that its economics must be favourable; that a workable and acceptable approach to waste management must be in place; and that novel reactor designs are developed to address current problems.

The RIIA Enquiry has as its central aim quantifying the question: "What is necessary to keep the nuclear option open?" It also aims to provide a base of balanced and reliable information for decision-makers. Already there are clear signs that nuclear power is returning to the international political agenda in response to concerns about climate change. For this return to consideration to lead to good decision-making in the near future, impartial information will be

essential. Phase 1 of the project has made a start on producing a source of such information. It has also helped the authors in their analysis of the principle issues, and has pointed the way to the more detailed work of the next stage.

Table 1. Differences between pro- and anti-nuclear positions.

Pro-nuclear position	Anti-nuclear position
Belief that major elements of the future are predictable; certainty about general projections of various energy sources. (For example, renewables demonstrably have the practical potential to remain only relatively minor players in world energy supply.)	Belief that major elements of the future are predictable; certainty about general projections of various energy sources. (For example, renewables demonstrably have the practical potential to dominate world energy supply.)
Absolutely certain about the future role of nuclear power (a major and important one), and issues such as nuclear waste (not a difficult technical problem).	Absolutely certain about the future role of nuclear power (no role at all), and issues such as nuclear waste (a technically insoluble problem).
Arrogance born out of belief in infallibility of own analysis.	Arrogance born out of belief in infallibility of own analysis.
Belief that the public is irrationally frightened of nuclear power. If only people could be properly educated they would become more pro-nuclear and support the nuclear industry.	Belief that the public is irrationally complacent about nuclear power. If only people could be properly educated they would become more anti-nuclear and support anti-nuclear campaigns.
Characterisation of opponents as either fools or charlatans.	Characterisation of opponents as either fools or charlatans.
Belief that government is not to be trusted to take wise decisions as it is too much influenced by the anti-nuclear media and pressure groups.	Belief that government is not to be trusted to take wise decisions as it is too much influenced by the nuclear industry and its supporters.

Table 2. Results of MORI opinion polling in the UK in 1999.

	Favourable towards nuclear energy	Unfavourable towards nuclear energy	Neither favourable nor unfavourable towards nuclear energy/don't know
Public opinion	28%	25%	47%
All Members of Parliament (MPs)	43%	44%	13%
MPs' perception of national public opinion	2%	84%	14%