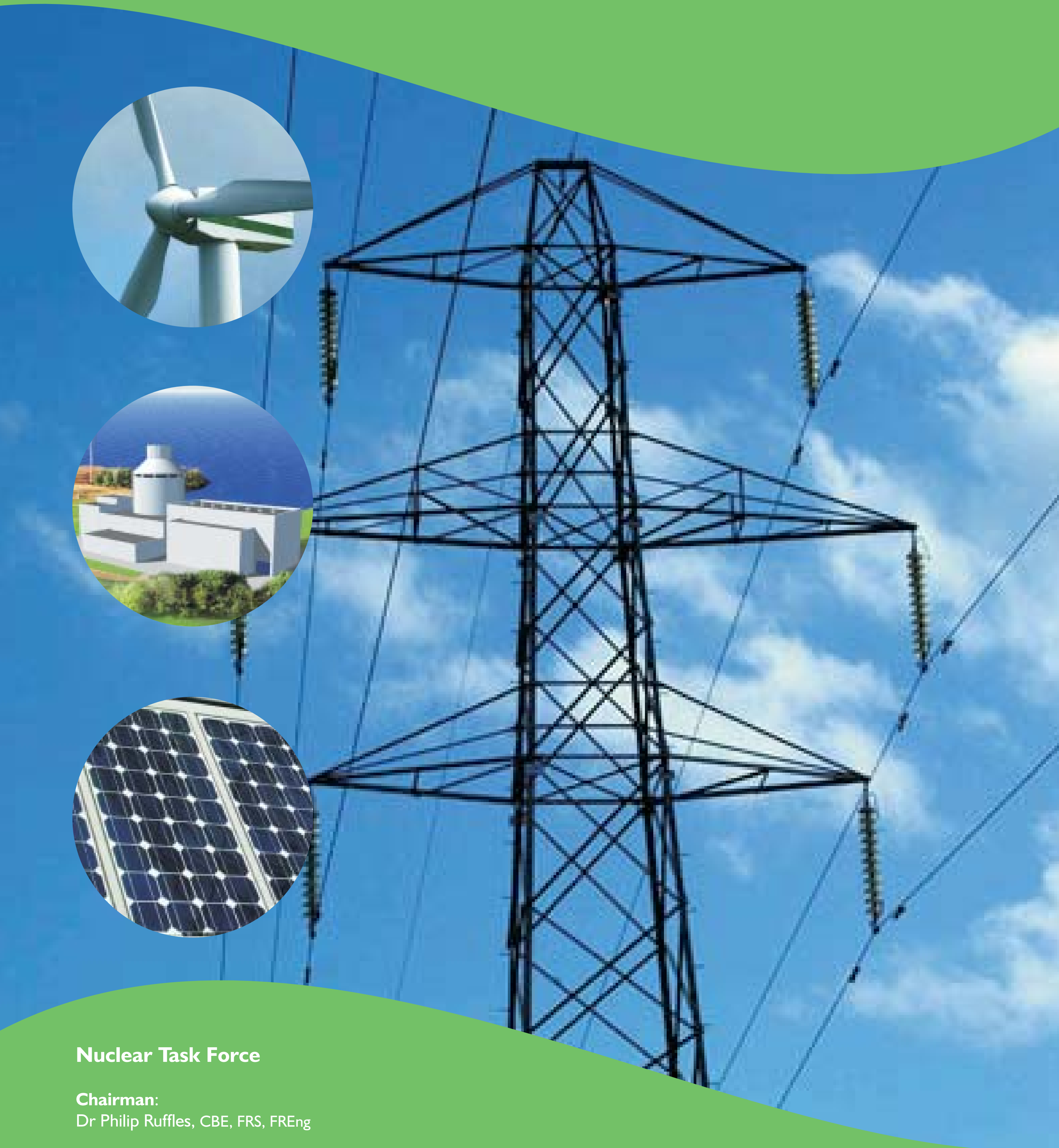
An Essential Programme to Underpin Government Policy on Nuclear Power



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Foreword

We are now facing a ***critical time*** in our history. Earlier this year the ***UK Government*** published its ***Energy White Paper***. In setting ***objectives*** for the next two decades it mapped out the *vision* of how the UK is going to ***meet its energy needs*** whilst tackling the ***challenge of climate change***. The intention is to shift the ***UK decisively*** towards a ***low carbon economy,*** and realise a ***60% reduction in carbon dioxide emissions*** by 2050.

To achieve these policy goals, action is proposed in the areas of energy efficiency, regulation, energy reliability through diversity and transport. For low carbon generation the technologies to be supported are renewables and combined heat and power (CHP). In the case of nuclear energy, a proven large-scale carbon free source of energy generation, the White Paper is non-committal by saying *"it does not propose new build or rule it out".* By implication, therefore the nuclear option is considered as insurance should the mechanisms proposed in the White Paper fail to deliver the carbon dioxide (CO_2) reduction targets at acceptable cost.

There have been many reports preceding and in response to the White Paper, by government committees, learned societies and institutions which are supportive of nuclear energy and outline what needs to be done to maintain the nuclear capability in the UK. However, the lack of a clear policy with respect to nuclear power has created a vacuum with respect to investment in R&D in support of existing power stations and in preparation for nuclear power as an option in the longer term. Consequently there is an increasingly worrying shortage of skilled scientists and engineers and serious concerns that the UK will further loose its technical skill base and absent itself from international programmes becoming a non-player.

The industry has firm views on what needs to be done to preserve the UK's nuclear capability, but realises that its perceptions and convictions need challenging, and what is ideally needed is an authoritative and totally independent review of the situation. It is for this very reason that British Nuclear Fuels plc (BNFL) has commissioned the work in this document.

The Authors are all independent, eminent experts and their report is intended to inform the debate about a way forward for nuclear R&D in support of the statements in the White Paper.

I welcome the report which proposes a practical and affordable way forward which, will place the UK in a much stronger position to make the right decisions regarding the future of nuclear power and to capitalise on the business opportunities that could follow if nuclear power is chosen as part of the UK's diversified carbon free generating capacity.

Dr Sue Ion OBE, FREng

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Executive Summary

UK Energy Policy

The UK Government has outlined its energy policy in the White Paper[1], "*Our energy future-creating a low carbon economy.*" This policy addresses the threat of climate change, loss of indigenous supplies of oil, gas and coal and the need to replace the existing infrastructure over the next 20 years to accommodate new electrical generating technologies. The central strategic objective of the policy is to move towards a low-carbon economy in order to reduce CO_2 emissions from current levels by 60% by 2050 with significant progress by 2020. We fully support this objective.

The primary means proposed to achieve this objective are a combination of greatly increased energy efficiency and use of renewables supplemented by increased use of gas fired power stations, together with a move to low-carbon fuel for transportation. In the longer term fusion is assumed to replace energy generated from fossil fuels. Nuclear power and clean coal technologies with carbon sequestration remain options.

However, these changes come at a time when the UK's indigenous natural resources of oil and gas will be substantially depleted, the existing nuclear power stations will reach the end of their life and coal fired stations will most likely be phased out. In this scenario, renewables are assumed to provide about 20% of electricity demand by 2020 making the UK dependant on importing up to three-quarters of its primary energy needs as gas and oil. This wholesale shift in approach to generation will need to be accompanied by significant changes to the grid infrastructure to accommodate both large central power stations and small scale decentralised power generation and to the infrastructure for gas supply.

The Risks Associated with the Policy

Without a secure and affordable supply of electricity, economic growth in the UK and our international competitiveness would be seriously jeopardised. A strategy that aims to provide this supply, whilst realising the significant reductions in CO_2 emissions by energy efficiency and renewable generating technologies alone, is both challenging and carries high risks. The White Paper quotes on energy efficiency and renewables "*they will have to achieve far more in the next 20 years than previously. We believe such ambitious progress is achievable but uncertain.*"

The Authors believe that the risks implicit in the energy strategy are very significant. If the risks materialise through either energy demand turning out higher than forecast or renewables failing to deliver the necessary capacity or both, there will be requirement for additional energy from fossil fuels and an increase in CO_2 emissions. Satisfying the targets through carbon sequestration is likely to be unacceptably expensive whereas these risks can be offset by nuclear power continuing to provide a substantial proportion of the carbon-free generating capacity, a point recognised by the White Paper which states, "*new nuclear build might be necessary if we are to meet our carbon targets.*" However in order to protect this option it is necessary to carry out preparatory work now.

The Need for a Nuclear Programme of Work

To ensure the maximum contribution to carbon free electrical generation, work is required to maximise the life of existing nuclear power stations, to protect the nuclear power option in the longer term and to address the legacy waste issue. In particular, it is necessary to acquire sufficient technology and know how to inform Government and industry decisions and to maintain the skill base as a starting point for any growth.

The main elements of the proposed programme are:

- To provide support for the existing nuclearstations
- To maintain competence to select, license and operate new reactor systems
- To keep abreast of international developments in the next generations of nuclear reactors and fuel cycles
- To maintain and develop competence in nuclear waste management including legacy clean up.

The total cost of the proposed programme is £20M per annum of which £10M is already committed to support legacy waste management with the balance to be co-ordinated and cost-shared between the public and private sector. The duration of the programme should be three years, such that at the end of this period Government and industry will be better informed to review the strategy to be followed for nuclear power in light of progress with other forms of carbon free energy. Action will also have been taken over this time frame to ensure the skills platform can be maintained ready for any growth, should it be needed.

In order to maintain focus, it is important that the programme is directed from a single point such as the new UK Energy Research Centre supported by a Nuclear Advisory Group.

1. Introduction

The Government has outlined its proposals for the UK's energy policy in the recently published White Paper[1] "*Our energy future-creating a low carbon economy*". The primary focus of this policy is to shift the UK decisively to a low carbon economy to address the concerns of climate change whilst at the same time addressing the implications of reduced oil, gas, coal and nuclear production. Within the next 20 years, the UK will become a net energy importer and will need to replace or update much of its energy infrastructure. The policy identifies three main challenges as part of the Government's vision:

Environmental - moving to a low carbon economy in which the UK takes a lead in cutting greenhouse gas emissions by 60% by around 2050. The recent reports by the Royal Commission on Environmental Pollution (RCEP)[2] and the International Panel on Climate Change (IPCC)[3], identified the need to reduce greenhouse gas emissions to these levels to tackle the causes of global warming. The targets are to be achieved by energy efficiency, extensive use of renewable energy sources and heavy dependence on gas, although coal with carbon sequestration and nuclear are not ruled out as fall back options. A move to carbon free technology for transport and the introduction of nuclear fusion for electricity generation are also assumed for the longer term.

Decline of UK's indigenous energy supplies – significant natural reserves will be depleted over the next two decades. Much of the UK's economically viable deep mined coal is likely to be exhausted within 10 years, by around 2006 the UK will become a net importer of gas and by around 2010 a net importer of oil. In the period to 2020 nuclear generating capacity, which today accounts for greater than 23% of demand, will have declined, through station closures, to less than 6%. The White Paper states that by 2020 the UK could be dependent on imported energy for three-quarters of its total primary needs, a greater dependency on imports than at any time since the industrial revolution 150 years ago with consequent security of supply and balance of payment implications.

Updating the UK's energy infrastructure – by adopting the policy, the UK will move to new electricity distribution networks to accommodate both large centralised and local distributed power generation from renewables and power sources in homes and businesses. It will also be necessary to provide additional connections to supplies of both piped and liquefied natural gas from different sources. In the longer term there will need to be changes to the infrastructure to support new fuels for vehicles operating on natural gas and, ultimately, hydrogen.

To address the new challenges, the White Paper sets out four goals:

1. To put the UK on a path to cut the UK's CO_2 emissions by some 60% by about 2050 with real progress by 2020
2. To maintain the reliability of energy supplies
3. To promote competitive markets in the UK and beyond, helping to raise the rate of sustainable economic growth and improve our productivity; and
4. To ensure that every home is adequately and affordably heated.

The White Paper states that the Government does not intend to set targets for the total energy or electricity supply to be met from different fuels. The preference is to create a market framework, reinforced by long term policy measures, which will give investors, businesses and consumers the right incentives to find the most effective balance to achieve the goals.

The Authors welcome the central theme of the energy policy, its goals and note its challenges. However the White Paper recognises that this energy policy involves significant risks and states with respect to energy savings and renewables that '*they will have to achieve far more in the next 20 years than previously*'. Recognising these risks, we consider that the possible contribution from nuclear power to solving the carbon problem should have been given greater emphasis. This view is shared by the House of Commons Science and Technology Committee in their paper 'Towards a Non-Carbon Fuel Economy: Research Development and Demonstration'[4] in which they state '*It (Government) has ducked the central issue-whether to provide a future for the nuclear power industry-and failed to give a lead*'

On nuclear power, the White Paper states:

"While nuclear power is presently an important source of carbon-free electricity, the current economics of nuclear power make it an unattractive option for new generating capacity and there are also important issues of nuclear waste to be resolved. This White Paper does not contain proposals for building new nuclear power stations. However we do not rule out the possibility that at some point in the future new nuclear build might be necessary if we are to meet our carbon targets. Before any decision to proceed with new build there will need to be the fullest public consultation and the publication of a further white paper setting out our proposals."

In the Authors' view, it is important that both industry and government are able to make informed decisions about nuclear power now and in the future. In addition, the contribution from existing nuclear stations to the UK's electrical generating capacity (and savings in carbon emissions) is significant and so safe and reliable continued operation of existing stations must be assured.

The Authors therefore propose the minimum necessary programme of work to be performed in order to:

- **maximise the life of existing stations,**
- **maintain the competence necessary to select, license and operate new reactor systems, including an independent economic assessment of nuclear power**
- **keep abreast of international developments in the next generation of nuclear reactors and fuel cycles and**
- **maintain and develop competence in nuclear waste management.**

This programme of work will maintain the skills, capabilities, knowledge and technology in the UK to underpin informed decisions and enable UK companies to participate in this large and growing global market.

The Task Force findings are discussed as follows. In Section 2 an assessment of the Energy White Paper is presented which highlights the risk of the proposed strategy failing to deliver. This argument leads to the view that the Government's wish to see the nuclear option maintained will only be realised if positive steps are taken to underpin it; the case is detailed in Section 3. The scope and funding of a proposed programme of work, including research, aimed at keeping the nuclear option open is presented in Section 4 with its method of implementation described in Section 5. Conclusions and recommendations are given in Section 6.

2. Energy Policy Risk Assessment

The Energy White Paper acknowledges that there are uncertainties associated with achieving the carbon reduction targets central to the UK's energy policy. This view is reinforced by the House of Commons Select Committee Report[4] that stated: *"There is no chance of achieving the Governments targets for CO_2 reductions if current policies and market conditions remain in place."*

Our view of the risks is outlined below using a model of the energy system now and in 2020.

2.1 A Model of the Energy System

The White Paper presents a scenario for the future energy system, together with the associated target reductions in carbon emissions, reproduced in Table 1, which total between 15MtC and 25MtC. The main components of the scenario are: increased energy efficiency, substantially greater use of renewable energy sources for electricity generation, increased use of low carbon fuels and eventually carbon free energy for transport and the use of trading permits as an incentive to reduce carbon emissions. The projected scenario also envisages an increased use of gas and a phasing out of nuclear and coal for electricity generation.

Table 1. Specific Targets Against Different Categories of Carbon Emission Sources

Category	Estimated MtC Reduction
Energy Efficiency in households	4-6
Energy Efficiency in industry, commerce and the public sector	4-6
Transport: continuing voluntary agreements on vehicles; use of biofuels for road transport	2-4
Increasing renewables	3-5
EU Carbon Trading scheme	2-4

The model, summarised in Table 2, used to assess the risks is based on the Energy White paper and on reports by the Royal Commission on Environment Pollution[2] and the Department for Trade and Industry (DTI)[5].

The derivation of the model is discussed in Appendix 2. Our model covers two cases for energy demand, before efficiency savings, of 0.5% and 1% per annum growth, both within the expected range. In both cases (Case 1 and 2a) we have back calculated the required efficiency savings in order to keep the net energy demand constant in line with the White Paper assumption. Case 2b also shows the impact on the higher level of demand if only the lower level (35TWh) of energy savings is realised. In this case, there is an actual increase in fossil fuel demand and an associated increase in CO_2 emissions assuming renewables and nuclear deliver in line with the White paper assumptions.

2.2 Elements of Risk:

(a) Demand and Energy Efficiency

Such estimates of demand for the future, as shown in Table 2, are inevitably subject to considerable uncertainty. Nevertheless they indicate that demand is likely to increase by between 35 and 73TWh. We believe that these RCEP and DTI projections could have under estimated the demand pressures particularly if, as anticipated in the White Paper, there is a move to electricity sourced energy such as fuel cells and advanced batteries in transport.

The White Paper assumes that the increase in demand for electricity can be more than offset by improvements in energy efficiency. However, economic incentives will be required to encourage new technology and changes in energy use; these are not clearly stated in the White Paper. On a practical level, the existence of a well-established and mature infrastructure in the UK means that reductions in consumption, (e.g. for space heating and services) will be constrained by the need for extensive back-fitting of energy saving measures. Moreover, in recent decades, there have already been considerable reductions in energy consumption in the industrial manufacturing sector as a result of considerable reductions in industrial activities. These trends are unlikely to continue into the future. With regard to transport, while considerable advance has been made in developing technology to improve the fuel efficiency of road vehicles, these have yet to feed through fully into production vehicles. If target reductions in energy efficiency of up to 73TWh are not achieved, on present policy this would have to be met by

Table 2 Electricity Demand in TWh

Year	Total demand without energy savings	Assumed energy saving in 2020 above 2002	Nuclear	Renewables	Fossil	Total including energy saving
2002	365	-	83	4.7 (thermal) 7.3 (other)	270	365
Case 1 2020	400	35	26	72	267	365
Case 2a 2020	438	73	26	72	267	365
Case 2b 2020	438	35	26	72	305	403

increased use of fossil fuels, most likely to be Combined Cycle Gas Turbine (CCGT) power stations which could increase annual CO_2 emissions by up to 7.3MtC[i], ie between one third and half of the planned savings.

In balancing out the demand and efficiency related factors, we consider that there is considerable risk that the electricity demand projected in the White Paper will be exceeded. Such an increase would require additional supplies from CCGT plants thereby placing the carbon emission reduction targets at risk.

(b) Renewables

As indicated in Table 2, the White Paper projects that renewables will supply 10% of UK electricity in 2010 and 20% in 2020, with an associated capacity requirement increasing from 10GWe to 20GWe. Recognising the uncertainty in these projections the White Paper proposes a review of progress in 2005/06. Furthermore, the White Paper suggests that if we are to achieve a 60% reduction in carbon emissions by 2050, the contribution from renewables could increase to 30% to 40% of our electricity generation and possibly more.

There are still significant questions to be addressed regarding such a rapid expansion to large-scale use of renewables. Established large scale generation technologies using fossil and nuclear fuels have well understood costs and the infrastructure required for their support is established. In contrast renewable technology does not have an established track record on a large industrial scale. Current information implies that the cost of renewables generation may be very high compared to costs for CCGT and modern nuclear plants. The Royal Society Report on Economic Instruments for the Reduction of CO_2 Emissions[6] suggests that electricity from offshore wind farms would cost around 6p/kWh, about three times the current cost of electricity.

The impact of demands on grid infrastructure from adopting major changes associated with these new technologies must be carefully evaluated. Moreover the environmental impact and public perception of renewables on such a scale is uncertain. While the issues of noise pollution and visual impact have been recognised, the impact on the biosphere is not known and further research is needed. Any shortfall in the projected supply from renewables will need to be offset by additional CCGT capacity with an associated adverse impact on carbon emission levels. For example a 5 percentage points shortfall to the 20% target in 2020 would add 1.8MtC.

Taking all of the uncertainties, namely technological, environmental and infrastructure (including back up capacity) costs into account, we consider the risks are very high of renewable energy generation not delivering the targeted levels of power, again resulting in associated threats to the carbon emission targets through the increased need for electricity from CCGT plants.

(c) Fossil Fuels

The White Paper proposes that CCGT plants can meet the balance of the electricity demand. Two figures for fossil fuel supply in 2020 are shown in Table 2 representing upper and lower bounds for the likely demand. For the upper case

[i] This is based on the assumption that 1TWh of electricity from CCGT produces 0.1MtC

(Appendix 2), the associated fossil fuel capacity is 56GWe in 2020 of which 46GWe will be by CCGT, requiring a substantial increase in capacity from the present level of 22GWe. This requires more than double the CCGT capacity to compensate for the closure of coal and oil fired power stations. Any upward variation in demand forecasts or shortfalls in other generation sources will add to this requirement.

In recognising the need for additional fossil fuel generation, the White Paper supports continued investment in clean coal technology and carbon sequestration (applicable to gas as well as coal) as insurance against increased demand without increasing carbon emissions. However such technologies, particularly sequestration, (without which the continued use of coal is not consistent with the carbon reduction targets), are not established and the benefits they could deliver have yet to be quantified. Furthermore, sequestration would be expected to increase costs considerably; the Royal Society Report on Economic Instruments for the Reduction of CO_2 Emissions[6] suggests that sequestration of CO_2 would lead to power costs of around 4p/kWh, i.e. more than doubling the cost of power from such units.

It is clear therefore that the various uncertainties surrounding the continued use of fossil fuels for electricity generation present significant risks to the energy strategy set down in the White Paper.

(d) Economics and Security of Supply

The increased use of gas raises concerns about energy security given that the dependence on imported gas, even on the basis of the White Paper's projections, could reach 75% with a majority coming from potentially sensitive regions such as Algeria, Kazakhstan and Russia. Such dependence for supplies of an essential component of our energy resource with associated uncertainties on prices clearly poses a further risk that is not addressed in the White Paper. Moreover, there are formidable technology challenges and associated costs of adopting the major changes in the UK's energy supply and demand pattern. These include costs for additional gas pipelines, updating infrastructure to support renewable, intermittent generation that is localised and also infrastructure to support fuel for new transportation systems.

Perhaps one of the greatest areas of uncertainty is the comparable cost of electricity generation from different technologies such as fossil, renewable and nuclear when all the costs are included. These issues are not fully addressed in the White Paper and there is a need to have a cost comparison that covers the total life cycle of each generation technology as well as the overall environmental impact.

A substantial increase in the cost of power generation presents an economic risk in that it would directly affect the UK's competitiveness and place a disproportionate burden on those least able to afford it. The Royal Society[6] estimates' imply that power from offshore wind farms costs about 3 to 4 times as much as that from CCGT units or modern nuclear plant. Thus, based on the Royal Society estimates', deriving power from CCGT units having CO_2 sequestration would present less of an economic risk than using offshore wind power. However, the even greater use of CCGT units would further exacerbate the problems of security of supply.

We consider that uncertainties in security of supply and energy costs present a significant risk to the objective of providing the UK's population with sufficient energy at an acceptable cost and also to the competitive position of UK industry in international markets.

(e) Carbon Emission Reductions from Non-power Generation Sources

The balance of the targets for CO_2 emission savings associated with UK energy consumption in Table 1 comes from transport. The objectives for transport in the White Paper concentrate on greater fuel efficiency, use of low-carbon fuels and ultimately carbon-free fuels. The move to different fuels will require investment in energy technology, production processes and in new infrastructure for energy supply. Again economic incentives will be needed to encourage such investment.

We support all of the objectives for changing the pattern of energy use in transport and consider them achievable over time and with the right economic environment. Nevertheless there remains much to do in the further development of the technology such as on hydrogen fuel cells and advanced batteries and the associated infrastructure requirements. Such a potential move to the so-called hydrogen economy requires carbon free electricity generation, to be consistent with the objectives in the White Paper.

We consider that these issues are not adequately addressed in the White Paper and that they present significant risks to the low carbon strategy particularly over the short to medium term (to 2020).

2.3 Conclusion

The cumulative impact of the risks associated with the energy strategy in the White Paper could easily lead to a shortfall against the carbon targets of 25% or more. This reinforces the need for an alternative means of delivering carbon free energy that is economically competitive. We believe that, as an established carbon free technology with a secure supply, nuclear fission can provide such an insurance strategy. However to retain this option requires action now to maintain the technological and skill base by pursuing a balanced energy research and development programme. The requirements for meeting this objective are considered in the remaining sections of the report.

3. Maintaining Nuclear Power as an Option

The White Paper recognises that nuclear power is currently an important source of carbon free electricity, but states that the current economics make it an unattractive option for new generation capacity and there are important issues of nuclear waste to be resolved. However, as discussed in Section 3.1, the generation costs from modern nuclear power stations in other countries are significantly lower than for the UK stations. Moreover evolutionary and new designs under development will achieve further reductions in electricity generation costs which will be significantly lower than the costs projected for renewables or coal with carbon sequestration. Modern plant designs also produce much less radioactive waste of a type that is easier to manage.

Thus we consider that the risks associated with nuclear power are overstated in the White Paper. Moreover, to maintain the nuclear option implied in the White Paper requires more proactive action now so that in three years time, when it is proposed to review progress with other forms of carbon free energy, notably renewables, both UK Government and industry are better informed to make decisions about the future for nuclear power.

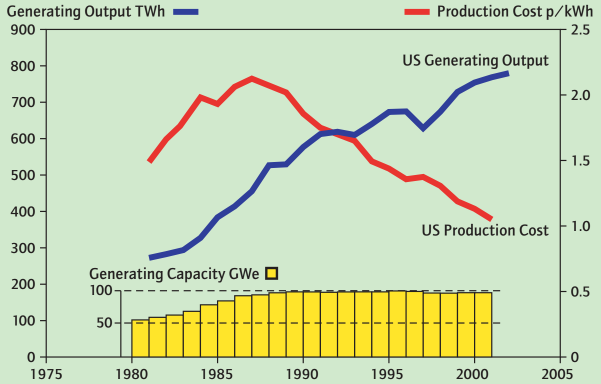
3.1 International Perspective on Nuclear Power

Nuclear power accounts for about 17% of the total electricity generated worldwide[7]. Since commercial nuclear power plants were first introduced in the 1960s, considerable improvements have been made in design and operating performance. Plant lifetimes are being extended, with 60 years becoming accepted as the objective for Light Water Reactors (LWRs). Nuclear power based on state of the art technology could deliver electricity reliably and at a competitive price in the UK (Appendix 3). A number of major industrialised countries, notably France, Japan, Korea and Russia are committed to developing their nuclear power base further by installing new plants. A review of the energy policies of different countries is given in Appendix 4.

The United States of America, after an effective moratorium on new build of 30 years, is actively considering restarting her nuclear power programme in order to meet energy requirements at a time when the issues of security of supply and climate change are growing in importance. An important lesson for the UK is that over this period the US maintained an investment programme in nuclear technology funded from both government and industry sources. Advanced technologies related to the lifetime management and reliable operation of ageing facilities have been tackled with support from the US Department of Energy. This has yielded significant dividends in terms of greatly improved performance and economics (Figure 1) and laying the foundations for extending plant operating lifetimes.

Emerging industrial countries, notably China and India, are also making substantial investments in new nuclear plant as a necessary contribution to meeting their energy growth requirements. These countries see nuclear power as an important factor in their continuing economic development by providing a source of plentiful and affordable electricity.

Figure 1. Historical Performance of US Nuclear Plants.



Production (Operating + Fuel) Cost is in p/kWh assuming £1 = $1.6 in 2001$

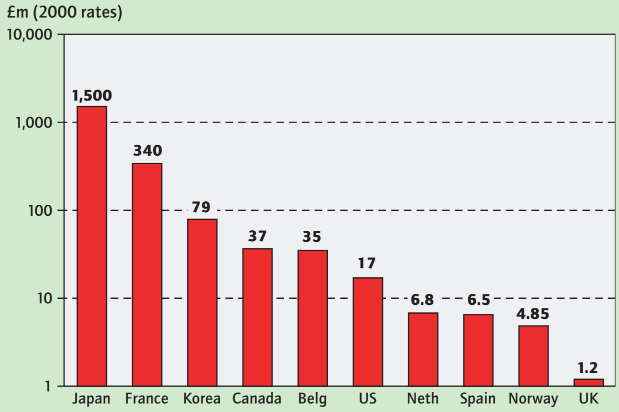
Data source: Nuclear Energy Institute's Industry Data Digest[8].

US Load Factor and Generating Capacity data from US Department of Energy Information Administration[7]. The inset graph shows that the generating capacity almost doubled between 1980 and 1988 and then remained roughly constant at just below 100GWe, illustrating the increase in output is due to improved operating efficiency.

Against this background there is a substantial international effort in developing new, improved reactor designs that combine simplified and more robust safety protection systems with easier construction and operation (Appendix 3). Next generation LWRs such as the advanced pressurised (AP) and advanced boiling (AB) water reactor designs are already undergoing a generic licensing process in the US. These designs are based on incremental advances on existing designs and thus (contrary to the impression given in the White Paper) the risks of failing to meet build and performance targets are correspondingly small. For the longer term, so-called Generation IV designs involving both water and gas cooled technology will go further in introducing innovative developments aimed at improving safety and performance. These advanced reactor development programmes are international, involving many countries with significant national programmes. There is a renewed and growing interest in High Temperature Gas-cooled Reactors (HTRs) with the advantage of inherent core safety characteristics and much better thermal efficiency. A particularly important development in this area is the Pebble Bed Modular Reactor (PBMR), which is being led by South Africa with UK industry support.

Government support for R&D to underpin nuclear power in many countries is much greater than that in the UK, even in countries such as Norway that does not operate nuclear power stations, or the Netherlands which has a small programme, Figure 2. Moreover in the US, where there has been a substantial decline in funding in recent decades, steps are being taken with congressional support to increase the investment in nuclear fission research substantially to an annual level of $240M[ii].

Figure 2 UK Public Expenditure on Fission R&D Compared to Other Nations (not including contributions to Euratom) [ii, iii]



Data averaged from Reference 9 and Reference 10 to account for slight discrepancies

3.2 The Current UK Perspective

Nuclear power currently provides about 23% of our electricity needs and also makes an important contribution to meeting our greenhouse gas commitments under the Kyoto convention. Much of this capacity is based on gas cooled reactor technology developed some 50 years ago and the early performance of some of the Advanced Gas-cooled Reactors (AGRs) was particularly poor. But, consistent with the US experience, significant investments in technology enhancements in the 1970s and 80s resulted in considerable improvements in performance over the last 10 to 15 years. On present projections, however, the UK's nuclear capacity will decline substantially over the next 20 years and thus the current benefit of zero carbon emissions will largely have been lost.

There has been a sharp decline over the last 15 years in the technical underpinning of our nuclear programme in terms of both R&D and the renewal of skills. The funding from UK industry for technology based R&D underpinning the operation of the civil power plants amounted to £30M in 2001/02. This level of funding is likely to decrease as the present stations reach end-of-life. Total government funding of fission

[ii] The US intends to increase expenditure to $240M as recommended by the US Nuclear Energy Research Advisory Committee (NERAC) in publication 'Long term Nuclear Research & Technology Plan', June 2000. This proposed increase is not shown in Figure 2.

[iii] Data for South Korea based on 2001 expenditure with £16M direct from Government and over £63M from the 'Nuclear R&D Endowment fund'. Further information available on the South Korean Institute of Nuclear Safety at http://www.kins.re.kr/eng/databank_7.html

nuclear R&D (leaving aside Ministry of Defence support for the nuclear submarine programme) over the same period was £5.7M[iv], with the UK's contribution of £4.5M to the EU Framework programme largely spent in the Joint Research Centres in other European countries whose programmes have little relevance to current UK needs. The impact of this low level of funding on the nuclear skills base was highlighted in a recent DTI sponsored study[11] that concluded that the UK will need to increase substantially the number of trained people over the next 10 years just to meet the needs of the legacy waste management programme alone. Preparatory work in support of a new nuclear construction programme would add to this need, see Appendix 5.

3.3 A Work Programme for the Next Three Years

The main requirements of a programme of work over the next three years are summarised below, by which time it would be appropriate for Government to complete its review of the nuclear option for new build.

Provide Support for the Existing Nuclear Programme - The existing nuclear power stations have a key role to play in enabling the UK to meet its targets for carbon emission reductions over the remainder of their lives. It is therefore vital that their performance is optimised in terms of both availability and lifetime. For example, premature closure of any nuclear capacity could threaten the carbon reduction targets through the increased use of fossil fuel sources to make up any shortfall in electricity supply. Continued investment in the underpinning technology will be required to maintain reliable operation.

Maintain competence to select, license and operate new reactor systems - An essential requirement in considering new plant options for adoption in the UK, is an objective and rigorous assessment of the key factors, including safety, environmental impact and economic performance. Moreover, experience shows that any design we choose to adopt will require some adaptation to meet our requirements, for example on licensing and operating parameters. We therefore must ensure that the necessary engineering and analytical skills are in place to make an informed assessment of candidate designs and to operate the plants safely and efficiently thereafter. Failure to do so would carry substantial risks.

Keep abreast of international developments in the next generations of nuclear technology reactors and fuel cycles - In the event of a shortfall in meeting the carbon emission targets and the consequent need to build new nuclear capacity, choices must be based on best current technology that combines robust safety and reliability with efficiency and economic performance. It is therefore essential that the UK maintains and strengthens its involvement in internationally developed designs aimed at both short term and longer term deployment such as systems that may emerge from the Generation IV programme initiated in the USA. To access such development programmes requires that the UK makes a real technical contribution. Buying into such international development programmes ensures that the UK will benefit from substantial gearing on our R&D investment.

Maintain and develop competence in nuclear waste management - A further important factor is the nuclear waste accumulated over almost 60 years of activities supporting both civil and defence applications. Whether or not there is a requirement for new build of nuclear power stations, there is a requirement to manage this nuclear waste liability safely and cost effectively. While the present arrangements for waste management are safe and secure, it is important to continue to invest in the technology to improve safety further, reduce costs and work towards implementing a long term strategy for the eventual disposal of intermediate and higher level waste. There is a major international effort in this area and it is vital that the UK maintains an active involvement in these international programmes, again benefiting from a gearing of our R&D investment.

In conclusion, we consider that the present position in the UK regarding the nuclear technology base and associated skills levels is not consistent with sustaining reliable operation of the existing nuclear stations while retaining the possibility of building new stations in response to any shortfalls in meeting the carbon reduction targets. While the nuclear industry has a responsibility, which it is meeting, to make a significant investment in these areas, this is not sufficient and it is vital that Government also invests in nuclear technology as part of its balanced energy R&D programme to underpin its energy policy objectives.

[iv] This figure is derived from Reference 9 which shows £0.85M spent by Department for Environment and Rural Affairs (DEFRA), £0.35M spent by the Engineering and Physical Sciences Research Council (EPSRC) and a contribution to Euratom programme of £4.5M. The Health and Safety Executive (HSE) Levy programme £1.2M is not included as this is levied on industry and therefore funded by the private sector.

4. Scope & Funding of the Proposed Programme

4.1 Scope

It is proposed that a technical and techno-economic programme be initiated on nuclear fission energy, covering the four main areas identified in Section 3. In what follows, outline technical activities are suggested for each area.

a) Providing Support for the Existing Nuclear Power Generation Programme

The continued safe and reliable operation of the UK's existing nuclear power plants requires the retention of core capabilities in the key technical areas. Since the Magnox and AGR reactor designs are unique in relation to the world population of nuclear power reactors, this places special demands on skills and experience. Although the Sizewell B Pressurised Water Reactor (PWR) is similar in basic design to the majority of the world's reactors and can therefore benefit from experience elsewhere, it is still necessary to maintain an appropriate level of expertise to meet safety and operational requirements.

The position regarding the three reactor types can be summarised as follows:

Magnox Reactors - These are now approaching the end of life and will be closed down within the next 10 years. It remains necessary to monitor plant behaviour and respond to issues promptly to ensure that safety requirements are met and plant availability is optimised during their remaining lives, consistent with economic performance. It is also important to anticipate future decommissioning and waste management requirements, and to develop operational procedures that will reduce the costs of these post-operational stages.

Advanced Gas-cooled Reactors (AGRs) - These 7 power stations have further operational lives of 8 to 20 years and there is a greater incentive to extend reactor lifetimes. However, life extension places additional technical requirements on understanding the behaviour of life limiting components, particularly if they are vital to safe operation. Two key areas for AGRs are graphite moderator integrity and boiler integrity.

Light Water Reactors (LWRs) - Although the UK currently operates only one PWR at Sizewell B any decision to construct new nuclear power plants within the next 15 years or so will probably be based on LWR technology. Moreover Sizewell B is expected to operate until 2035 and if we follow international trends as for example, in Japan and the US, this may extend to 2055. The major benefits from having an internationally adopted design are the well-established information exchange networks reporting problems and sharing of development programmes to improve operational efficiency and life extension.

Key Technical Areas

- **Reactor core physics**: A specific requirement is to maintain and update physics codes to reflect new data on core behaviour and to take advantage of modern computing methods. There is also the need to maintain fuel performance and handling codes.
- **Materials ageing**: As plants get older they experience a range of problems related to ageing of components and materials. A specific issue for the UK's gas cooled reactors is degradation of the graphite moderator due to irradiation damage and oxidation. International experience is showing that degradation of core structural materials could be a life limiting problem on LWRs.
- **Radiation chemistry**: Considerable work has been done on coolant chemistry control and effects on components in both AGR and LWRs. Radiolytic oxidation of graphite is a particular issue for AGRs. In LWRs stress corrosion cracking of both circuit and core structural materials is the main issue.
- **Inspection and plant condition monitoring**: This is a key area for assuring the structural integrity of components such as reactor pressure vessels and circuit components. Such assurance is required for safety justification as well as availability and life extension. Key developments include greater precision in flaw detection and a move to on-line monitoring of components.

The UK needs to retain core capabilities in all of these areas for the continued operation of the UK's existing nuclear power plants, including the naval submarine reactors. Such capabilities will also be essential in the event of new plants being introduced in the future. On the international stage there are substantial collaborative programmes particularly in support of LWRs and it is important that the UK is able to obtain maximum benefits through participation in such joint programmes.

Resources

While the prime responsibility for maintaining existing power plants falls to the generating companies, it is appropriate for government to provide some support to reflect the achievement of national policy objectives. This is consistent with the practice in our main industrialised competitor countries having nuclear power and with the Government's practice on fossil and renewable energy sources.

We suggest a programme of research on the topics outlined above to underpin existing industry programmes would require an additional minimum resource of around 35 people with a cost of around £1.5M per annum (around £4.5M over 3 years).

b) Maintaining Competence to Select, License and Operate New Reactor Systems

A decision to build new nuclear power plants in the UK would require procurement from overseas vendors, although it is expected that domestic companies would play a significant part in the construction. As emphasised in Section 3 a rigorous assessment will be required, particularly of the key factors relevant to the UK regulatory and market conditions. Validation of vendor performance specifications and safety justifications supported by the regulator are key requirements in reducing perceptions of risk and gaining both public and investor confidence.

The main technical competencies required to conduct such an assessment would include:

Socio-Economic Assessment - The White Paper raised the economic performance of nuclear power as an issue. It is clear therefore that economics and competitiveness are key issues in considering the future deployment of power sources and a comprehensive independent economic study will be essential. Areas likely to be covered in such studies include assessments of:

- Ability to meet energy policy targets of sustainable, economic power generation.
- Socio-economic and macro-economic benefits to local regions and impacts on local communities.
- International comparisons of nuclear power economics and relevance to UK
- Stakeholder involvement
- Public perception

Safety Analysis - Safety analysis is an essential part of the licensing process, but is determined by national requirements. Specific studies would be needed in order to ensure that new systems meet the UK licensing requirements. It would be more efficient if generic licensing were to be adopted for the chosen system, as is being adopted in the US rather than licensing on an individual plant basis, but this requires action by the UK regulator.

Performance Assessment - Reactor vendors will generally provide a performance specification. As a customer, the UK would need to carry out the necessary analysis to validate the vendor's claims.

Resources

There has been a significant decline in the UK in the analytical and assessment skills base required for selecting and preparing for construction of a new nuclear station. Based on experience with previous assessments, the most recent being Sizewell B, we estimate that a minimum base for keeping current options under review under the above headings will require around 50 people, costing approximately £2.5M per annum (£7.5M over three years). In the event of a decision being made to order new stations this team would have to be significantly increased

c) Keeping Abreast of International Developments in the Next Generations of Nuclear Reactor Systems

As emphasised in Section 3, to obtain access to the international collaborative projects on new reactor systems it is necessary for the UK to offer real technical contributions. The financial gearing benefits from such participation are important, but equally vital is the experience gained from direct participation in the design and associated technical development work. Only through such involvement can we both influence the programmes towards meeting specific national goals and benefit from innovations that may be applicable to today's systems. To meet these national objectives there is a need to move from the present ad hoc position where resources to support UK involvement come from individual companies with nuclear interests, to one where Government plays a more direct role both in national co-ordination and in providing financial support.

The main features of the international programmes are summarised below.

Modular Systems Available for Commercial Deployment 2010-2020

Pebble Bed Modular Reactor (PBMR) - Eskom, the Industrial Development Corporation of South Africa and BNFL, formed a partnership in 2000 to develop the PBMR. The partnership anticipates that these reactors will be built initially in South Africa and the United States for commercial power generation. The modular design of PBMR aims to meet tight economic targets for lifetime costs. It also has inherent safety features associated with the core design, low environmental impact and is able to be deployed in countries that do not necessarily have the infrastructure required for large scale nuclear systems.

International Reactor Innovative and Secure (IRIS) - Westinghouse formed an international consortium of vendors, energy companies, and universities in 1999 to develop the IRIS reactor for deployment by about 2015. The countries involved are Brazil, Italy, Japan, Mexico, Spain, the United Kingdom, and the United States. IRIS is a novel light water reactor design with a modular, integral primary system. The objective of the design is to provide more robust protection against severe core accidents together with high availability and economic performance.

Advanced Systems Available Post-2020

Generation IV – This programme was launched in late 2000 by the US Department of Energy to identify, assess and develop new nuclear energy systems which could make significant advances in sustainable energy development, safety, reliability, waste management, proliferation resistance, and economics. The programme is also supported by the main nuclear countries (nine in total including France, Canada and Japan) with funding from their governments reflecting the programme's long-term strategic importance. The EC has also decided to contribute a small number of personnel from its Euratom budget.

In the UK, the DTI has supported the Generation IV initiative in principle from the beginning, but has left it to the UK's participating companies (BNFL, British Energy and NNC) to fund their own involvement and find the resources. BNFL have provided the majority to date. This is unsustainable going forward, as the return and pay back from this type of programme lie out with the commercial return from companies and are the preserve of governments.

Generation IV is highly important to the UK to ensure access to future energy options, whilst sharing the costs with the international nuclear community and to give access to work on advanced fuel cycles which has relevance to waste management and clean-up. Skills and capability maintenance, which are key benefits from the Generation IV programme would be denied without direct UK participation.

Range of skills

To be involved in these collaborations requires maintenance of a modest domestic research programme in areas where we can claim leadership or where the skills and knowledge retention in the UK would be most valuable. For example:

- The long-term performance of materials for reactor construction and nuclear fuel manufacture.
- Radiation chemistry relevant to reactor coolants.
- Reactor and nuclear physics.
- Thermal hydraulics.
- Engineering technologies relevant to nuclear reactor component design and manufacture.
- Control, instrumentation and analysis.
- Advanced fuel cycle processes with relevance to legacy waste and clean-up.

Resources

The UK contribution to participation in the above international collaboration programmes would involve about 50 professionally qualified science and engineering staff and university researchers at a cost of £5M per annum. This size of R&D investment seems reasonable when compared to that proposed to address legacy waste management (Section 4.1d).

d) Maintaining and Developing Competence in Nuclear Waste Management

The UK Waste Legacy - has arisen from a variety of past military and civil programmes dating back to the 1950s. The Magnox prototype and civil power reactors were not designed to minimise the waste volumes and they account for some 85% of the existing nuclear waste liability in the UK. An important factor is the instability of the fuel elements in water storage ponds requiring them to be reprocessed. The waste volumes from AGRs are less than for Magnox stations, particularly because the fuel elements are stable and the option exists for long term storage prior to eventual disposal. However, the operational and decommissioning waste is still significantly larger than LWRs because of the lower power density and the need to deal with the graphite fuel element sleeves and moderator.

Modern Light Water Reactors - produce much less waste than the UK's gas cooled reactors; approximately 90% less than that from Magnox reactors. Spent fuel from the Sizewell B reactor and any likely type of new-build LWR reactors is stable and can be stored wet or dry - probably for as long as 100 years. The main source of intermediate level waste is the ion exchange resins used for coolant chemistry control. Several nations have well-developed waste management research and development programmes looking, eventually, to direct deep geological disposal of spent fuel. The R&D need is therefore much less than for legacy wastes and should be based on international collaboration.

Plutonium - Although the UK plutonium stock is currently stored securely and safely under international safeguards, there is strong international pressure to minimise the potential proliferation and terrorist threats. There are two routes for reducing the UK stockpile; use it as a mixed oxide fuel in a new PWR reactor or treat it as a waste. France and Japan, who only operate LWRs, have a well established policy of reprocessing spent fuel and recycling as mixed oxide in their power reactors and this option is therefore potentially available to the UK. The alternative approach is to regard plutonium as a waste and immobilise it for eventual disposal, for example by incorporating it into high level vitrified waste for eventual deep disposal in rock formations. The UK can benefit from participation in collaborative programmes on both options.

There is European collaboration on incineration (transmutation) in fast neutron systems of plutonium (CAPRA) and minor actinides and long-lived fission products (CADRA). BNFL lead the UK contributions (with AEA-T and NNC). This programme allows the UK (through BNFL) to demonstrate that it is addressing these concerns.

Decommissioning Wastes – These comprise reactor components and large volumes of mostly very lightly contaminated soils and construction materials

Key Technical Areas

Legacy Waste - A research programme aimed at improving management of legacy wastes needs to cover:

- Improved procedures and approaches for the retrieval of stored wastes.
- Better instrumentation and new handling techniques for characterisation and separation of complex waste prior to conditioning.
- New processes and waste forms for conditioning reactive and mobile wastes to render them passively safe.
- Improved methods for packaging, long-term safe storage and ultimately disposal.
- Discharge reduction from conditioning processes
- Environmental pathways, impact and risk assessment.
- Design and location of sub-surface facilities for storage or disposal
- Socio-political issues relating to public attitudes to waste and its disposal.

New Reactor Wastes - New reactors are likely to be built to designs that are replicated in many different countries. The development of technology for waste management can be (and already is being) shared effectively. It seems likely that long-term storage and direct disposal of spent fuel elements rather than reprocessing will be the core strategy. It should be noted that several elements of the Legacy Waste Programme are relevant to new reactor wastes.

We therefore consider that this programme should focus on:

- Involvement in international programmes by direct participation.
- Long-term spent fuel storage in the context of UK conditions.
- Spent fuel packaging for disposal.

Resources

For research and development work on the legacy waste problem, the estimated technical resource is 200 people at an annual cost of £10M. Since the UK Government currently spends £700M per annum on managing legacy wastes (a responsibility shortly to be assumed by the Nuclear Decommissioning Agency, NDA), R&D expenditure of this order is a sound investment. The main objectives should be a robust analysis of options to give assurance on the way forward and significant overall cost reduction together with an accelerated programme delivering greater safety sooner.

For waste management R&D work relevant to new reactors, a deployment of around 20 people at an annual cost of £1M would be appropriate. This work would allow government to make a judgement on the specific waste disposal implications of purchasing new reactor systems together with participation in international programmes.

4.2 Skills

It is anticipated that around 355 qualified scientists and engineers, including economists and sociologists, would be employed on the proposed programme outlined in Section 4.1.

Appendix 5 summarises the background to the skills crisis in nuclear fission in the UK and shows approximately how the additional qualified people needed for the programmes would be deployed in the four requirement areas. This nucleus of skilled people, including new recruits, could provide a necessary foundation for starting a new nuclear fission programme if this is needed. In any event the majority of the staff are required to maintain the existing systems and to deal with decommissioning and waste disposal.

4.3 Programme Costs

The total cost of the proposed programme is summarised in Table 3.

Of the £60M total programme over three years, £30M is a continuation of money already being spent by industry on waste management. Assuming that this is to continue, the remainder of the programme requires £30M. Excluding the contribution to Euratom, the current public sector funding is £1.2M per annum and it is assumed that this funding and research programme could be re-directed to contribute to the new programme.

We do not feel it appropriate for us to make recommendations on the division of the source of the funding between Government and industry but we do see a need for a significant commitment from Government to ensure that the programme takes place. Recently, there have been some positive indications of the interest in public funding of nuclear R&D, such as the sustainable energy initiative (SUPERGEN) by the Research Councils. This initiative is welcome, although

Table 3 Cost Summary of the Proposed Programme.

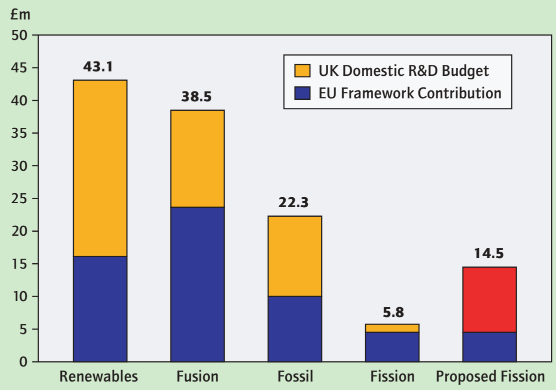
Category	Annual Funding £M/y	Manpower / Man years	Duration / years	Total over 3 years £M
Providing Support for Existing Nuclear Programme	1.5	35	3	4.5
Maintain competence to select license and operate nuclear systems	2.5	50	3	7.5
Keeping abreast of international developments in next generation nuclear ractors and fuel cycles	5	50	3 initially	15
Maintain and develop competence in nuclear waste management	11	220	Ongoing	33
Total	**20**	**355**		**60**

as noted by the House of Committee Science and Technology Committee[4] '*The Research Council's expenditure on energy research has been pitiful and this investment [SUPERGEN] is a step in the right direction. But it only remains a step, which we hope will be followed up vigorously in the future. If UK technologies are to succeed the scale of investment must increase rapidly.*'

4.4 Comparison with Funding for Other Carbon-Free Sources in the UK

It is relevant to compare the additional resources proposed here to the total UK Government spending on Energy Research, Development and Deployment. We estimate that in Financial Year 2000/2001 the total spend amounted to roughly £100M[9]. A breakdown of this spending into the different areas is shown in Figure 3.

Figure 3 Total Annual Public Sector Funding for Energy R&D in the UK[v].



Data from Reference 9. Also shown is the proposed programme of £14.5M per annum which is £4.5M for the UK contribution to Euratom plus the proposed programme given in Table 3 less the industry funded nuclear waste programme. Note industry / government funding split is not shown.

It can be seen that the largest share goes to renewables and this area is set over the next few years to receive over £250M as identified in the White Paper[vi]. The other major component is for fusion research of which a large proportion is the UK's contribution (£23.5M per annum) to the Euratom Fusion programme[9]. The government expenditure on fission includes a £4.5M per annum contribution to Europe leaving approximately £1.2M available for expenditure of direct benefit to the UK, this is not included in the proposed programme in Table 3. Against this background, the proposed level of expenditure seems appropriate as an integral part of a balanced energy R&D programme taking into account that being spent on other forms of energy generation.

[v] Renewable energy R&D budget is estimated at currently just over £40M comprising £16M EU contribution and for the domestic programme approximately £15M from the DTI, approximately £6M from research councils, approximately £4M from DEFRA and the Carbon Trust with others contributing such as the Tyndall Centre and Building Research Establishment contributing less than £1M. Further details in Reference 9.

[vi] The White Paper states that a substantial renewables support programme worth £250M between 2002/03 and 2005/06 has been put in place and this will be further increased by £60M. This is additional to the extra funding announced in the 2002 spending review which allocated an additional £38M for energy policy objectives in 2005/06 compared to 2002/03. The White Paper also states that the Carbon Trust will be spending £75M over the next 3 years.

5. Programme Implementation

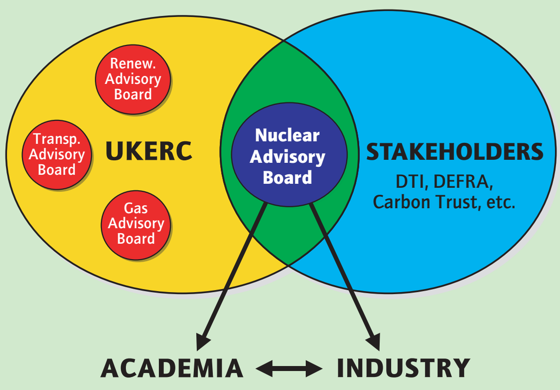
Currently, public sector funding of energy projects encompassing R&D, including nuclear fission, is provided through a number of government agencies: DTI, Office of Science & Technology, DEFRA, Carbon Trust, Energy Savings Trust and Tyndall Centre. In its response to the White Paper the House of Commons Science & Technology Select Committee[4] noted that, '*Britain's energy structures are too complicated. As a result efforts to stimulate R&D are fragmented and directionless. No public body or minister is taking responsibility for driving forward technological innovation and deployment*'. The Committee also advocated '*Much bolder action is needed to make non-carbon technologies play a significant contribution to the UK's energy mix.*'

Consistent with the Select Committee's findings, the Authors believe that the formation of an Energy Authority would ensure that a coherent strategy for the future of energy technologies is provided with a single government department having accountability and the funding to ensure delivery. Whether or not this happens, a strategy for nuclear fission is needed and we consider that a programme of work as outlined in Section 4 should be implemented. As well as providing national insurance against a possible future need for additional nuclear power, it would also provide a clear incentive for other stakeholders and particularly industry to invest in nuclear technology.

We support the move announced in the White Paper to set up a UK Energy Research Centre (UKERC) as recommended by the Chief Scientific Adviser's High Level Group on Energy Research Development and Demonstration. Such a Centre should provide the focus for a more clearly defined and co-ordinated energy development programme. Three Research Councils (EPSRC, ESRC, and NERC[vii]) have been awarded £28M under a programme entitled "Towards a Sustainable Energy Economy", and have been tasked with establishing the UKERC and an associated network linking relevant stakeholders. The UKERC will be a hub for providing a national focus, and could also provide a focus for UK activity in Europe. The Government expects this Centre to play a key role in facilitating collaboration with industry and UK participation in international projects.

With regard to nuclear fission R&D, it is vital that it is part of a balanced national energy programme and it should be included within UKERC's remit. We envisage that UKERC would need to be supported by Advisory Boards one of which would oversee the nuclear programme defining the research, commissioning it and ensuring it is properly delivered. It would work closely with all stakeholders to ensure that their requirements are being satisfied. The proposed arrangement is shown schematically in Figure 4.

Figure 4. Proposed Relationship between UKERC and Other Stakeholders and a Nuclear Advisory Board.



[vii] EPSRC is the Engineering & Physical Sciences Research Council, ESRC is the Economic and Social Research Council and NERC is the Natural Environmental Research Council

6.Conclusions and Recommendations

We recommend that the UK Government should build on the outcome of the Energy White Paper and take action to mitigate the risks associated with key areas of its strategy related to realising the carbon emissions targets and ensuring greater security of supply at competitive energy costs. The only proven source of energy generation that mitigates all of these risks is nuclear power. This requires active steps to maintain the UK nuclear capability including keeping as viable, the option for new build through investment in a modest nuclear programme, the core of which is nuclear R&D. Without such a programme there is a real risk that the option would not be effectively available if and when needed. The programme would focus on the following areas:

- Provide support to the current nuclear programme to maximise the life of existing stations including work on materials ageing, radiation chemistry, reactor physics and plant instrumentation and monitoring.
- Maintain competence to select, license and operate new reactor systems covering socio-economic analysis, safety analysis and performance assessment.
- Keep abreast of international developments in the next generation of nuclear reactors and fuel cycles through collaboration including the Pebble Bed Modular Reactor (PBMR), International Reactor Innovative and Secure (IRIS) and Generation IV.
- Maintain and develop competence in nuclear waste management, notably retrieval, discharge reduction, environmental pathways and socio-political assessments for legacy waste and long- term storage, packaging and disposal for new build.

The research programme should aim at gaining leverage on nuclear R&D through international collaborative ventures. It is therefore important that the UK Government gives positive commitment to its involvement.

The total cost is £20M per annum (and would involve approximately 355 people) of which £10M is already committed to support legacy waste management with the balance to be co-ordinated and cost-shared between the public and private sector. While the private sector has committed moderate funding to some of research topics proposed here, many of the research areas are long term and benefits lie beyond any normal commercial planning horizons. As evidenced by other nations, sponsorship in the proposed areas is normally the preserve of governments. This new funding is considerably larger than the present public sector funding of nuclear research in the UK of £1.2M. It is recognised that part of the cost will be covered by cost sharing with industry.

This programme should be performed as part of a national strategy for nuclear energy and managed by the recently announced UK Energy Research Centre. We recommend that programme content be developed involving all appropriate stakeholders from government, industry and academia through a Nuclear Advisory Board that would be responsible for determining the content of the nuclear programme and reviewing its progress.

Appendix 1.
Members of the Fission R&D Task Force

Chairman

Dr Philip Ruffles CBE, FRS, FREng

Philip Ruffles was formerly a main board member of Rolls-Royce plc from 1997 to 2001 responsible for Engineering and Technology. He is a non-executive Director of Domino Printing Sciences plc and Diamond Light Source Ltd and Council Member of the Central Laboratory Research Council. He has received many awards and distinctions for his contribution to engineering including the Mac Robert Award (1996) and the Prince Philip Medal (2001) from the Royal Academy of Engineering and was awarded the CBE in 2001.

Members

Professor Michael Burdekin FRS, FREng

Michael Burdekin was Professor of Civil and Structural Engineering at UMIST from 1977 to 2002. He is Chairman of the Nuclear Industries Technical Advisory Group on Structural Integrity (TAGSI), and was a member of its predecessor, the Marshall LWR Study Group, from the early 1980s. He was Deputy Chairman of the Management Advisory Committee for the Inspection Validation Centre operated by UKAEA for the Sizewell B reactor inspections. He served as a member of ACTRAM on transportation of radioactive materials and as an advisor to IAEA on the same topic. He has acted as a Consultant to MoD on aspects of Nuclear Steam Raising Plant. He has received various medals and awards from and given a number of prestige lectures to Professional Institutions.

Professor Charles David Curtis. BSc, PhD, FGS, CGeol, OBE.

Charles Curtis was Professor of Geochemistry, Head of Department and Research Dean in the University of Manchester. Involvement with the nuclear industry was initiated by an invitation to join the Royal Society's working party on the Nirex Repository programme in 1993. He is now Chairman of DEFRA's Radioactive Waste Management Advisory Committee, RWMAC and a member of UKAEA's Board Advisory Committee (Health, Safety, Security and Environment). He has served as a NERC Council Member, President of the Geological Society and is presently Research Professor of Geochemistry in Manchester. He was awarded the OBE in 2001 for services to environmental protection.

Dr Brian Eyre - CBE, DSc, FRS, FREng

Brian Eyre was appointed as UKAEA Board Member in1987 with responsibility for the Authority's nuclear programmes. He became Deputy Chairman in 1989 and Chief Executive of UKAEA in 1990. He subsequently became Deputy Chairman on the Board of AEA Technology following privatisation in 1996 and remained as until retiring in 1997. Since retirement he has been visiting professor in the Materials Department at the University of Oxford and was Chairman of the Central Council Laboratories of the Research Councils from 2000 to 2001. Brian Eyre was awarded the CBE in 1993, elected as Fellow of the Royal Academy of Engineering in 1992 and as Fellow of the Royal Society in 2001.

Professor Geoff Hewitt FRS FREng

Geoff Hewitt spent most of his career in the nuclear industry, working at the UKAEA Harwell Laboratory from 1957 to 1990. He became Professor of Chemical Engineering at Imperial College, London (part time from 1985, full time from 1990, Emeritus from 1999). He has specialised in multiphase flow and heat transfer with applications ranging from nuclear reactors to process heat exchange, from hydrocarbon recovery to multiphase flow metering. He continues to be active in research in these areas and in energy and engineering education policy. He was elected Fellow of the Royal Academy of Engineering in 1985 and Fellow of the Royal Society in 1990. He was President of the Institution of Chemical Engineers in 1989/90.

Dr William Wilkinson - CBE, FRS, FREng

Dr Wilkinson read chemical engineering at Cambridge. After a period with the UKAEA he became Professor of Chemical Engineering at Bradford in 1967. He re-joined the nuclear industry with British Nuclear Fuels in 1979. He was appointed Engineering Director in 1982 and elected to the Main Board in 1984. He was a Director of Pacific Nuclear Transport Limited, Urenco Ltd., BNFL Inc. and Allied colloids plc. He has served on the Science Research Council, the Advisory Council on Science and Technology and the Radioactive Waste Management Advisory Committee. He is a Past President of the Institution of Chemical Engineers. He was elected to the Royal Academy of Engineering in 1980 and to the Royal Society in 1990. He is currently a Consultant and a Visiting Professor of Chemical Engineering at Imperial College.

Appendix 2.
Energy Policy Risk Assessment

A2.1 Basis of risk assessment model

The assessment of risks in Section 2 is based on information contained in the White Paper itself and on data in the DTI's Digest UK Energy Statistics (DUKES)[12] for 2002, on the Report of the Royal Commission on Environmental Pollution[2] and on the DTI Energy Forecast Paper EP68[5]. It is necessary to consider actual power delivered in relation to production of CO_2 and electrical generation capacity in relation to the ability to meet peak power demands.

A2.2 Overall demand

The results of the model for electricity demand in 2020 based on these figures are shown in Table A2.1, reproduced in Section 2 as Table 2.

The figures for demand for 2002 have been taken from the DTI's Digest UK Energy Statistics (DUKES)[5] for 2002 – Gross Supplied Electricity, giving a final total consumption for the year of 365TWh. Any estimates for future demand are inevitably subject to significant uncertainty. The Royal Commission on Environmental Pollution (RCEP) report[2] states that annual energy consumption will rise between 0.5% and 1% per annum in the absence of any improvement measures. The DTI's EP68 paper[13] predicts primary energy demand growth of 1% per annum up to 2010. Our model covers two cases (1 and 2) for energy demand, before efficiency savings, of 0.5% and 1% per annum growth, respectively. Based on DTI and RCEP figures without counter measures, the electricity demand would be likely to grow by a factor of between from 1.1 to at least 1.2 from 365TWh in 2002 to between about 400 and at least 438TWh by 2020. The White Paper suggests that overall demand will be reduced, despite new demands, through energy efficiency improvements. In the Table, the figure for total energy demand in 2020 is shown as the same as for 2002 assuming that the White Paper forecast is just met. In both cases (Case 1 and 2a) we have back calculated the required efficiency savings in order to keep the net energy demand constant in line with the White Paper assumption. Case 2b also shows the impact on the higher level of demand if only the lower level (35TWh) of energy savings are realised.

A2.3 Generation Capacity

Indicative figures for electricity generating capacity are shown in Table A2.2. For the whole of the UK, the installed capacity on the grid for 2002 is given by DUKES[12] as about 74.0GWe excluding 6.0GWe off grid capacity. Based on an electricity growth prediction of 1.1 to 1.2 and allowing for some reduction in present over-capacity, the installed capacity would have to remain roughly constant at about 74GWe. This is consistent with the DTI's EP68 Report[5], which predicts capacity in 2020 will be just over 70GWe.

Table A2.1 Electricity Demand in TWh

Year	Total demand without energy savings	Assumed energy saving in 2020 above 2002	Nuclear	Renewables	Fossil	Total including energy saving
2002	365	-	83	4.7 (thermal) 7.3 (other)	270	365
Case 1 2020	400	35	26	72	267	365
Case 2a 2020	438	73	26	72	267	365
Case 2b 2020	438	35	26	72	305	403

Table A2.2 Installed Capacity in GWe

Year	Nuclear	Renewables	Fossil	Others	Total
2002	13	0.1 on grid 0.9 generation off grid	56	4	74
2020	4	10 (EP68)	56	4	74
2020	4	20 (Implied by White Paper)	46	4	74

The basic comments given above concerning electricity demand apply equally to generation capacity. The reduction in nuclear power capacity shown in Table A2.2 is based on the known programme of plant closures. For renewables, the White Paper states that the 10% target for supply will require 10GW of capacity by 2010 and sets an aspiration for doubling this by 2020. It has to be taken into account that renewable power sources are generally intermittent in nature and hence there is a need for alternative base load supply or for some form of storage.

The EP68 report predicts that total fossil capacity will remain roughly constant although coal will reduce to 10GWe and oil will be phased out. The difference will be made up by gas fired generation with a prediction in 2020 that gas will be 46GWe and coal 10GWe giving a total of 56GWe. However the White Paper implies a capacity of 20GWe for renewables by 2020 with a consequent reduction in fossil fuel capacity.

Currently the UK has about 22GWe of CCGT and 35GWe of conventional power supply capacity[12] (made up of 25GWe coal, 3GWe oil, and 7GWe mixed). The EP68 report assumes in 2020 there will be no oil and only 10GWe of coal. On the basis of the EP68 estimates for 2020, with a total capacity of 74GWe the fossil fuel capacity must be 56GWe. This will require 46GWe of gas supply using CCGT. With a current CCGT capacity of 22GWe this would mean installing a further 24GWe of CCGT capacity by 2020.

Appendix 3.
Factors Relevant to New Nuclear Power Reactors in the UK

This Appendix summarises the current position on nuclear power technology together with likely developments, which will be relevant if nuclear power is to become a future option for deployment in the UK.

A3.1 Economics

Capital cost

Plant capital cost is the most significant cost that needs to be addressed for nuclear power which currently accounts for about 70% of the total generating cost of electricity. A key factor in this is the interest charges because of the high rate of return demanded for financing nuclear capital projects in deregulated markets due the high perceived risks, notably:

- The long timescale for construction and the perceived risk of project cost overruns.
- The risk of government interference and lack of coherent, long-term government policy and reassurance.
- The perceived risk of technical problems which could affect completion or subsequent performance.
- The availability of low risk energy investment options in competition with nuclear, for example CCGT systems.
- The need to cover first time engineering and licensing costs for the first of any innovative reactor design.

Thus prerequisites for re-establishing nuclear power as an option of choice for electric utilities worldwide are a significant reduction in capital cost together with a reduction in the cost of capital.

Extensive development programmes are being carried out in several countries where the key objective is to reduce capital cost. To achieve such reductions, step changes are needed to reduce complexity, mainly through reductions in the number of individual reactor components and safety protection systems and also in the quantities of bulk materials needed when compared with currently operating plants. Examples of next generation of LWRs that have been derived from well proven technology to achieve these aims include AP600/1000, System 80+ and ABWR. For example capital costs calculations for AP1000, the Westinghouse advanced passive design which builds on well proven Pressurised Water Reactor (PWR) technology, have been developed using actual component, material, and labour quotes to give a high degree of assurance. Independent analysis of these costs by the Electrical Power Research Institute (EPRI) in the US and also in the UK by Rothschild has confirmed the validity of the cost calculations for the building of a series of reactors in the UK. The generation cost elements are presented in the following Table A3.1.

Table A3.1 Contributions to Total AP1000 Generation Costs (in 2000 money value[13])

Generation Cost Elements	Contribution To Cost, p /kWh
Capital Cost	0.425
Financing cost	1.025
Fuel	0.325
Operations and Maintenance	0.625
Spent fuel management	0.050
Decommissioning	0.050
Total	2.50
Assumptions: 40-year plant lifetime, 8% after tax discount rate, and 90% plant availability	

Construction Schedules

Construction times in the past have been long and variable in the UK and elsewhere. This has had a significant effect on the perceived risk in nuclear projects and consequently a detrimental effect on the economics of generation. However significant improvements are now being made in construction techniques, mainly in the Far East. Korea is currently constructing four reactors, Japan has three reactors under construction and China currently has five. These countries are all benefiting from series construction that helps to reduce the project scheduling risk. These successful build programmes have a number of features in common, notably;

- An indigenous operating organisation where intelligent customer capability is maintained.
- Plants are built in a series based on a common design.
- Learning is maximised to achieve cost-effectiveness by staggering the build programme (typically by 1 to 2 years between each reactor).

In France the nuclear energy programme has also benefited from committed series construction to spread first-of-a-kind production cost and project schedule risk. At its peak in the early eighties, the French nuclear industry was adding to the grid an average of six 900 MW units per annum.

In the US the nuclear industry has selected standardised designs for detailed first-of-a-kind engineering studies. The US programme jointly funded by industry and the Department of Energy (DoE) has been completed which gives prospective buyers firm information on construction costs and schedules. The AP1000 has a projected site construction schedule of 36 months from first concrete to fuel loading. Such a schedule is much shorter than previously experienced because of the reductions in bulk materials, components, and building volumes. In addition, extensive use of factory-built modules facilitates reduction in project schedule and reduces the risk of over runs.

Licensing

Licensing creates potential uncertainties in timescale and cost of building and operating nuclear plants and therefore presents additional risk to investors, vendors and operators. This has been a particularly significant issue for the UK and following the time (10 years) and cost (£30M) it took to satisfy planning and licensing requirements for Sizewell B there has been a significant barrier to new nuclear build.

In the US the approach to licensing has evolved to a very different position from that in the UK. A generic certification system is now in place and is being applied to the new next generation designs. This approach is the result of an extensive public process regarding licensing which means that provided safety issues within the scope of a certified design have been fully resolved, the design will not be open to legal challenge during the licensing process for particular plants. Utilities will be able to obtain a single licence to both construct and operate a reactor before construction begins. This generic licensing approach greatly simplifies the process and this helps greatly to reduce the risk and uncertainty associated with separate costly public inquiries for each new build site.

A3.2 Safety

Advanced next generation reactors are improving the robustness of safety protection by moving to passive systems that use only forces, such as gravity, natural circulation and compressed gas to shut down the reactor if the need arises. This removes the need for the active intervention of pumps, fans, diesel generators or other machinery in loss of coolant events. A further advance will come from moving to reactor core designs that have inherently safe shutdown properties in the event of core events such as loss of coolant and control rod operation. The Pebble Bed Modular Reactor (PBMR) is an example of an inherently safe design.

A3.3 Waste Management

Waste Management for a new nuclear power programme

Modern PWRs generate about a tenth of the waste per unit of power generated compared with Magnox reactors. Furthermore, all LWRs use stable fuel consisting of a uranium ceramic oxide clad in zirconium which is inherently much more stable than the magnesium alloy clad uranium metal fuel used in Magnox reactors.

Wastes from any new build PWR reactor programme in the UK would be handled very differently from historic programmes. Because of its stability there is no requirement to reprocess the spent fuel. It can be safely stored in a simple and well-understood manner using ponds or dry cask facilities. These facilities can be located at a reactor site, or in a central location with storage depots above or below ground. The fuel can be stored for over 100 years in this form without the need for intervention

Waste disposal

Whilst many countries are pursuing interim storage, there is wide international agreement amongst scientists and engineers that eventual geological disposal offers the best safe long-term solution for nuclear wastes and some countries have already made significant progress in establishing permanent geological disposal sites. In Sweden, Finland and the US, concepts have moved from the research and design phase to actual construction. All designs have in common the goal of stable, passively safe storage of fuel for an indefinite amount of time. In some cases fuel will be encapsulated prior to disposal, in others it will be simply placed in an over-pack. Whichever process has been selected these have been agreed internationally as acceptable disposal routes and containment of the wastes with insignificant environmental impact is predicted for tens of thousands of years.

As far as the UK is concerned we agree with the position stated in the DEFRA consultation document on waste management:

The first requisite for success is to gain public trust in the science and technology of the disposal concept. Thereafter follows the problem of public agreement on site selection. Consultation is again of paramount importance, as is the recognition of the service being provided by the local community. In order to make progress in defining a long-term waste management policy acceptable to the public, the Government has launched a major consultation process ("Managing Radioactive Waste Safely", DEFRA 2000).

Appendix 4.
Energy Policies in Other Countries Relating to Nuclear and Renewable Technologies

A4.1 US Energy Policy

Even though the United States has the largest number of operating nuclear reactors (109) delivering the largest capacity (100GWe) in the world, the research and development underpinning the continued development of this energy source has been reducing for over a decade. It is only recently that US Government has reversed this trend recognising the importance of nuclear technology. Funding for nuclear fission has dropped significantly in the US from a peak of $2500M (2001mv) per annum in 1979 to a low of $21M (2001mv) per annum in 1998[10], excluding $350M on the civilian high-level radioactive waste programme, and the environmental management clean-up programme. Recently however, the situation has now been reversed and funding is starting to increase again.

In FY1999, the Department of Energy was able to win Congressional support to begin a modest programme ($19M) to explore the design of the next generation of nuclear power plants. The DoE hopes that this funding level will increase to become a significant programme. Specific programmes in the US addressing future nuclear energy developments are Nuclear Energy Plant Optimisation (NEPO), Nuclear Energy Research Initiative (NERI) and Nuclear Energy Technologies (NET). Under the NET programmes comes NP2010 and Generation IV. A brief outline of the programme is given below;

NEPO – Nuclear Energy Plant Optimisation programme, is aimed as improving plant reliability, availability and productivity as well as enabling current plants to operate up to and beyond their initial license period. Some of the benefits of this programme are highlighted in Section 3.

NERI – Nuclear Energy Research Initiative, is a joint programme between industry, universities and national labs looking at nuclear energy technology such as new reactor designs, improved safety etc. International NERI agreements have been signed with South Korea and France and are now focussing on establishing agreements with Japan and South Africa.

Nuclear Power 2010 – Is an initiative aimed at government working with industry to help improve the licensing and regulatory requirements associated with constructing a new nuclear plant around the 2010 timeframe

Generation IV – Is aimed at developing, in close co-operation with international partners, next generation nuclear energy systems, which represent significant improvements in all aspects of nuclear power technology.

In 1998, the DoE established the Nuclear Energy Research Advisory Committee (NERAC) to provide advice to the DoE on nuclear technology programmes. The NERAC recommended development of a long-range R&D programme focusing on developments required over the next 10 to 20 years with a significant increase in the proposed R&D funding. There are proposals that US will need an additional 50GWe of nuclear capacity over the next 2 decades.

For renewables, in the AEO2003 reference case[14,15], despite improvements and incentives, grid-connected generators that use, renewable resources are projected to remain minor contributors to US electricity supply. They are forecasted to increase from 298TWh in 2001 (8.0 % of total generation) to 495TWh in 2025 (8.5 % of generation).

A4.2 Japanese Energy Policy

Nuclear R&D funding in Japan is significant and accounts for 86% of government investment in energy R&D. Typically funding for fission reactor systems R&D is around £350M including Light Water, Fast Breeder reactors and High Temperature gas-cooled reactors[10]. Funding for R&D for supporting fuel cycle infrastructure is typically £1100M. Japan is committed to keeping nuclear central to its electricity generating policy with the expectation of 9 to 12 new plants operating by 2010.

Japan's total energy needs fulfilled by renewables are projected to be, for the reference scenario, 5.1% by 2020. The percentage of electricity generated by renewables in the reference scenario is 9% by 2020[16]. To meet its Kyoto target, only 3% of total energy must be from renewables by 2010 due to high nuclear generation capacity.

A4.3 French Energy policy

In France the nuclear sector accounts for over 90% of government financed energy R&D. In 2000 spending on nuclear fission R&D totalled £340M[10] with the main topics being current and advanced reactors, nuclear fuel cycle and nuclear safety related work. France has a co-ordinated and long-term advanced reactor programme which includes Light Water Reactors, Gas Cooled Reactors, Liquid Metal Fast Reactors and Molten Salt Reactors. The programme includes collaborative agreements with US, EU, Japanese and Russian governments.

France is taking part in the European initiative "Take off campaign" for renewable energy sources, launched recently by the European Commission. France is also committed to reach the 21% level of renewables by 2010 (within the frame of the future European Directive on renewables on the electricity market)[17].

A4.4 South Korean Energy Policy

South Korea uses a combination of thermal (oil, gas, and coal), nuclear, and hydroelectric capacity to meet its demand for electric power. Total power generation capacity was 50GW as of the beginning of 2000. The South Korean government estimated in May 2002 that its electricity demand will rise at an average annual rate of 3.4% per annum through 2015[18].

The programme aims to develop solar thermal energy, photovoltaic power, fuel cells, etc., in order to increase the percentage of renewable energy in its total energy mix from 0.6% in the mid-1990s to 2.0% in 2006.

Under the Kyoto Protocol, South Korea is not required to accept greenhouse gas emissions targets. Nevertheless South Korea believes that increasing its nuclear capacity over the next 15 years will contribute to a reduction in carbon emissions.

In South Korea government spending on nuclear fission R&D increased significantly in 1995 although this subsequently reduced following the economic downturn in 1997. In the late 1990s funding was £23M split approximately 50:50 between fission and fusion. The fission R&D budget accounted for approximately 13% of total energy R&D in South Korea. However the government has ambitious plans for nuclear energy R&D with a planned £3.4bn to be invested through to 2010 with £1bn to be generated from the government's nuclear R&D fund, which is a levy from nuclear generation of 1.2won per kWh.

A4.5 Swedish Energy Policy

The Swedish 2002 energy policy[19] states:

- Encourage the production of electricity from low environmental impact and renewable sources, by means of a system based on the issue and trading of certificates determined by the source of electricity.
- To examine if it would be appropriate to reach an agreement for the controlled, responsible phasing out of nuclear power production.
- To reduce the emissions of greenhouse gases by 2 0 1 0 to be at least 4% lower than they were in 1990.
- To restructure taxation on energy to raise taxes on environmentally undesirable activities.

The use of renewables in Sweden accounted for 26% of the primary energy supply in 1998, one of the highest rates in the European Union[20]. The main renewable contributions come from hydropower and biomass. In 1998, electricity from hydropower amounted to 76TWh. This is 48% of the country's electricity production. During 1998, use of bio-fuels, peat etc. amounted to 92TWh. Bio-fuels now meet more than 50% of the supply to the district heating grids.

Recent cold winter weather following a dry summer in 2002 has strained capacity and raised electricity bills in the Nordic region. Spot prices on the Nordic power bourse Nord Pool hit record highs in December 2002 with prices of 544.34 Norwegian crowns per megawatt hour, almost five times the May 2002 average and almost three times the average for December 2001. This has caused some manufacturing to halt or slow production.

This energy crisis comes at a time when Sweden is enacting law to shutdown its nuclear stations following a 1980 Swedish referendum aimed at replacing nuclear with renewable generation. The 600MWe Barseback-2 nuclear station is due to close by the end of 2003, although the government has proposed a new set of measures to the parliament over the future of the reactor, after admitting that conditions necessary for enforcing the unit's closure before the end of 2003 'cannot be met'. The new measures also call for the Barseback-2 closure issue to be included in general discussions about a nuclear phase-out[21].

A4.6 German Energy Policy

Germany has relatively insignificant domestic energy sources and is heavily import-reliant to meet its energy needs. In 1999 electricity generation comprised coal 47%, nuclear power 30%, natural gas 14%, renewable sources (including hydro) 6%, and oil 2%[22]. However, oil accounted for 41% of total energy consumption.

Energy policy in Germany is influenced heavily by EU regulations. The EU requires privatisation and competition in member countries' energy markets, and Germany has been a leader in developing competitive energy markets.

Following reunification of the country in 1990, the major task of German energy policy was to merge successfully the radically different energy sectors of the East and West. West Germany had a diversified and mainly privately-owned system of energy supply with a high standard of energy efficiency and a commitment to environmental protection. In contrast, East Germany's energy sector was highly centralised, predominantly state-owned, and mainly dependent upon relatively "dirty" lignite (brown coal) as its primary fuel. To date, a great deal of progress has been made in conforming the former East Germany's energy sector to the standards of the West in the areas of privatisation and environmental regulation.

The German Government has made climate protection one of its key policy issues. A 25 % carbon dioxide reduction target by the year 2005 compared to 1990 levels has been announced[23]. In 1998 the use of renewables in Germany reached 284PJ of primary energy demand, which corresponds to a penetration rate of 2% of the total primary energy demand or 5% of the total electricity demand. By 2010 the German Government wants to double the contribution of renewable energies to the total energy demand.

A4.7 Swiss Energy Policy

In Switzerland about 40% of the country's electricity comes from nuclear power and 60% from hydro. This section does not cover the Swiss energy policy in detail, but highlights some recent developments concerning nuclear power.

The Swiss parliament has accepted a proposed new law providing for the nuclear option to be 'kept open', ahead of two anti-nuclear initiatives considered in a referendum on 18 May 2003.

The outcome of the referendum is that Swiss voters have rejected two anti-nuclear proposals which were originally put forward in 1998. "Electricity without Nuclear" was overtly to phase out nuclear power by 2014, while "Moratorium Plus" would have led to a similar outcome by removing incentives to invest in and upgrade nuclear plant. Two thirds of voters rejected the first proposal and 58% rejected the second, with practically all Cantons refusing both.

A4.8 Belgian Energy Policy

Belgium's nuclear phase-out law may be revoked by the incoming government after the defeat of the country's Green parties in general elections on 18 May 2003. The country's nuclear phase-out legislation, originally agreed in July 1999 by the liberal-led government and its coalition partners including the Green party, calls for each of Belgium's seven reactors to close after 40 years of operation with no new reactors built subsequently. However, as the law was being passed, many members of parliament including some from the main government parties were promising they would vote its revocation as soon as a government without the Greens was in power.

Appendix 5.
Nuclear Skill Base and Expertise in the UK

A5.1 Current Situation

The UK nuclear skills base and research infrastructure have been in steep decline over the past few decades. Historically, the UK has a wealth of valuable experience in the design, construction, licensing, commissioning and operation of nuclear plant. Much of this experience resides in individual people, many of who are in the later stages of their careers. Without action the UK is in danger is of being unable to retain the skills and capabilities needed to ensure the nuclear option is available. This point is reinforced by a recently issued paper by the House of Commons Science and Technology Select Committee entitled 'Towards a Low-Carbon Fuel Economy'[4] that states '*It is hard to imagine the nuclear skills situation improving, since the White Paper has all but ruled out new nuclear build. Even with no new build, nuclear engineers will be needed for many years to come to deal with decommissioning and storage but few graduates will be inspired to join an industry in its death throes*'

A5.2 BNFL University Research Alliances

In an attempt to reverse the downward trend, in 1997 BNFL embarked on a strategy of establishing University Research Alliances (URAs) with the aim of underpinning key areas of nuclear technology in the UK. To date four URAs have been established in Radiochemistry (Manchester), Particle Technology (Leeds), Immobilisation (Sheffield) and Materials (UMIST). In total these alliances will undertake £40M worth of R&D and support a skill base of about 140 university researchers over the next 5 years. All the new centres have new, permanent staff appointments, including 4 professors. These centres serve a number of purposes, such as:

- Conducting fundamental research to support current operations that are outside the R&D remit of industry.
- Developing innovative solutions for the future.
- Raising the profile of nuclear technology in universities.
- Helping to maintain the supply chain of technical people required by the industry.

These alliances are already well positioned to carry out research in the technology areas that cross-cut a number of aspects of nuclear technology. In addition to the URAs, there are a number of universities currently providing post-graduate teaching in nuclear technology such as Birmingham with MSc courses in the Physics and Technology of Nuclear Reactors and Radioactive Waste Management and a proposed MSc course at Manchester in nuclear technology. Funding from the Research Councils and the Office of Science & Technology in support of these courses is low and as a result universities such as Birmingham and Manchester have resorted to innovative partnerships involving industry in order to fund such courses.

A5.3 Specific Skill Needs

While an excellent start has been made by BNFL in establishing the URAs more needs to be done to support nuclear technology and encourage regeneration of skills needed to keep present facilities operational and maintain the option of assessing and deploying future nuclear systems. Such skills require hands-on familiarity with plant, which can take a number of years to gain given the nature of working safely on complex plant to strict license conditions.

An estimate of the numbers of staff, which might be necessary, by skill type is given in Table A5.1 for each of the four general areas for the research programme proposed in Section 4. The overall total amounts to 355 qualified and experienced people.

Table 5.1 Summary of Skills Requirements

Main skill area	Skills	Supporting existing nuclear programme	Competence to select, license & operate new systems	Keeping abreast of international developments	Competence in nuclear waste management		Total skills
					Legacy waste	New waste	
Chemistry	Radiation chemistry	4	3	3	20	2	**32**
	Graphite chemistry	3		2			**5**
	Corrosion chemistry	4	2	2	20	2	**30**
Materials	Radiation damage	3	5	2	2	2	**14**
	Fuel technology	3	5	3	2		**13**
	Fracture mechanics	4	2	3			**9**
Engineering	Chemical engineering (separation technology)			3	35		**38**
	Remote inspection	3	2	3	25	2	**35**
	Safety & risk assessment	3	7	5	10	3	**28**
	Thermal hydraulics		5	4	5		**14**
	Control & instrumentation		3	4			**7**
Physics	Nuclear physics	4	4	5	2		**15**
	Health physics	2	3	2	10	2	**19**
Earth Sciences	Geology				30	3	**33**
	Environmental impact assessment	2	4	3	30	2	**41**
Socio-Economics	Social science		2	3	4	1	**10**
	Economics		3	3	5	1	**12**
Total		**35**	**50**	**50**	**200**	**20**	**355**

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