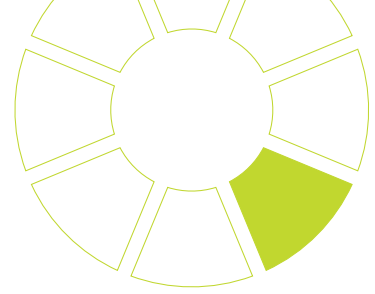




THE FUTURE OF NUCLEAR ENERGY IN THE UK

Birmingham Policy Commission

The Report
July 2012



Foreword

by the Chair of the Commission



It was a great honour to have been invited to chair this policy commission for the University of Birmingham.

This is a critical time for the UK to get its energy policy right as we face the twin challenges of climate change and energy security.

Historically nuclear energy has had a significant role in the UK and could continue to do so in the decades ahead. But this is by no means inevitable and, as a former minister for energy, I am more than aware of the complexities involved in getting energy policy right now and for future generations.

The current report looks at challenges facing the UK in terms of building up its nuclear programme. It examines technology, financing, safety and waste issues, supply chain potential, workforce requirements and R&D.

Our report makes clear that unless the Government shows a decisive lead and creates the right conditions for investment in the UK, the country risks losing out on its huge potential for developing a new nuclear industry.

The University of Birmingham has a long and established track record working in the areas of de-commissioning, health monitoring and residual life prediction for existing nuclear power stations, dating back to the first phase of nuclear construction in the 1950s.

Birmingham has also made significant contributions in metallurgy and materials in the study of the extension of the lifetime of reactor materials; important contributions have also been made in the field of radiation damage to nuclear materials.

It is therefore in an excellent position to contribute to a nuclear renaissance in the UK, illustrated by its recently opened 'Centre for Nuclear Education and Research'.

I would like to express my great thanks to members of the Policy Commission for their invaluable contribution. We owe a great debt to Professor Martin Freer, who has been a tower of strength in leading the work; and I would also like to give my thanks to Audrey Nganwa for her excellent support.

Philip Hunt

Acknowledgments



The last twelve months, over which the Policy Commission has attempted to develop a coherent understanding of the complexities associated with nuclear energy, the impediments to a nuclear renaissance, energy policy, waste management and public opinion, have been extremely stimulating. This journey has been made all the more rewarding by the high quality input received and numerous enlightening discussions. The University wishes to express its sincere gratitude to all those who have contributed and helped shape the thinking found in the report.

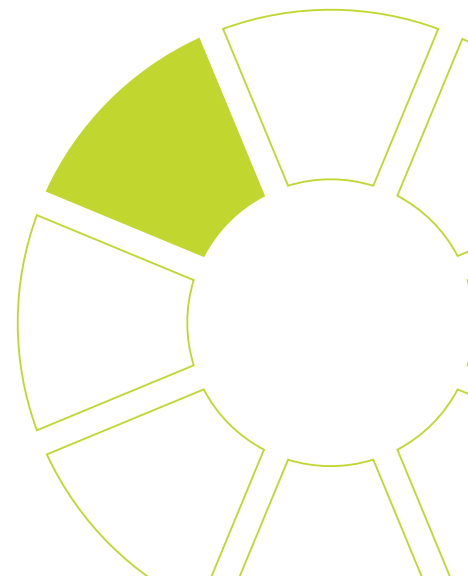
There are many who have devoted a considerable amount of time to the work of the Commission. These include the Commissioners, who have steered the direction with their tremendous knowledge of nuclear energy and policy, Lord Philip Hunt, who ably chaired the Commission, demonstrating impressive clarity, and everyone who contributed to the individual meetings, workshops and debates.

The Commission greatly appreciates the quality of the input from those who attended its evidence gathering sessions.

At the heart of any successful process are organisation, planning and efficiency. In this regard Dr Audrey Nganwa, the Policy Commission's Research Fellow, was the lynchpin in ensuring the Commission reached a successful conclusion. Contributions from Dr David Boardman, Brigid Jones, Kirsty Mack and the University Communications Team are also greatly appreciated.

The views expressed in this report reflect the discussions of the Commission and the input received and do not necessarily reflect the personal views of those who contributed.

Professor Martin Freer



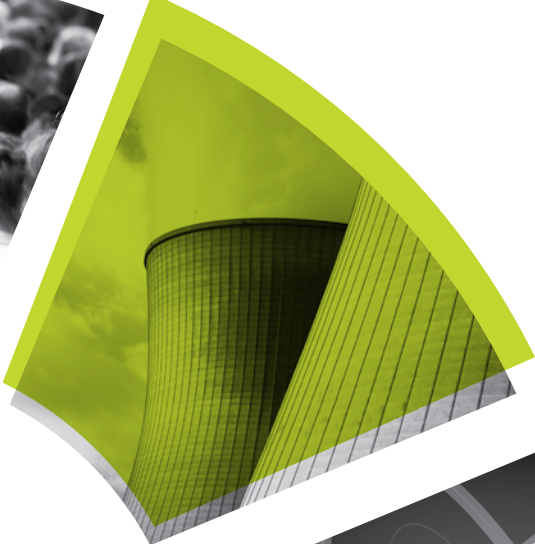
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Section I

Setting the context



Nuclear energy:

Is it part of the UK's future?

How will nuclear energy be a key part of the UK's future energy landscape?

There are many challenges facing the UK, perhaps none greater than the present international financial crisis. But looming just over the horizon is one that will rival it – the energy crisis.

Driven by the need to address climate change and energy security, the UK is reshaping its energy portfolio. In a bid to decarbonise energy production, renewable energy sources are taking centre stage – coupled with efforts to increase energy efficiency. Nevertheless, it is widely believed that such sources alone cannot meet the full UK demand. Other low carbon sources will be required. **Energy policy-makers face a trilemma – they may have to choose between policies that will raise the cost of energy, reduce its security of supply, or worsen its impact on the environment.**

Many countries are revolutionising the way they generate energy, but for the UK – with its high population density and relatively high per capita use of electricity (compared to the world average) the situation is more acute than for many. At a time when demand is predicted to increase, the UK's current nuclear power stations will be approaching their design lifetimes – the last is due to close in 2035. In addition, many coal power stations are to be closed as controls on various emissions are tightened. Combined, these two sources account for nearly 50% of the current UK electricity production. This will create a significant gap between supply and demand that, unaddressed, will have dramatic

consequences. Is enough being done and fast enough to fill the gap in the UK's energy portfolio? Herein lies the challenge for both Government and those who seek to influence policy alike.

As part of the solution, the Government has a stated aim of encouraging the continued use of nuclear energy, a tried and tested technology shown to be one of the lowest emitters of greenhouse gases and that would contribute to the UK's security of supply through providing a significant fraction of the country's base load electricity. Importantly, at the political level, there is cross-party support for maintaining a significant proportion of nuclear in the UK's future energy mix. In terms of new construction, ten or more reactors are under consideration based on two alternative designs – the Advanced Passive Reactor (AP1000) from Westinghouse¹ and the European Pressurised-Water Reactor (EPR) from Areva,² both capable of producing energy for a period of up to 60 years and enabling the UK to replace its current ageing reactor fleet with the very latest 'Generation III' technology. Indeed, a major worldwide collaborative effort is currently underway to develop future 'Generation IV' reactors that target increased sustainability, proliferation resistance, very high levels of

¹ Westinghouse: AP1000 <http://www.ap1000.westinghousenuclear.com>

² Areva: EPR <http://www.areva.com/EN/global-offer-419/epr-reactor-one-of-the-most-powerful-in-the-world.html>

safety and efficiency and reduced waste production. A number of advanced designs are being investigated, with demonstrator plants foreseen or already under construction in a few countries, including France, the USA and China, with plans to introduce commercial reactors within the next 20 to 30 years. Though the long-term international trajectory of Generation IV development is uncertain, the world's leading civil nuclear power nations are engaging strongly in cooperative pre-commercial research in order to address the technical challenges. However, the UK currently has limited involvement – significant active participation in such research came to an end approximately five years ago when Government funding ceased. Is this the right approach?

There are a number of significant hurdles that must be overcome in developing the UK's nuclear agenda, as reviewed within this report. A range of issues need to be addressed:

- What is UK energy policy? What is the roadmap for nuclear energy in the UK?
- What are the difficulties in creating the right economic climate for utilities to build new power stations?
- Given past failures, can nuclear power stations be built to budget and time?
- Is public opinion sufficiently resilient to accept a major new build programme in the aftermath of the safety concerns raised by the accident at Fukushima?
- Are nuclear power stations really safe and what is the public perception?
- Is there a skilled workforce that can construct, commission and operate new power stations and develop and operate the associated current and future fuel cycle facilities?
- Is the UK's approach to waste disposal robust?
- Does the UK have a joined-up policy on the future fuel cycle requirements as well as management of the plutonium stockpile?

The 'leave it to the market to decide' approach, where Government relies on energy companies to determine the energy mix, results in the temptation of the energy companies to focus on the near term, perhaps through a build up of gas-fired power stations. However, the use of nuclear energy requires a long term national commitment entailing many decades of responsibility, and a country should foresee an elapse of at least 100 years between the initial planning and the final decommissioning of the latest power plants, not to mention the management of long-lived radioactive waste and stewardship of disposal sites. Furthermore, being a finite resource, uranium also raises questions of long-term sustainability of reserves. These questions must be addressed now so that the technological foundations can be laid to keep future options open. In this regard:

- Will the UK still be looking to build current day nuclear technology in 30–40 years time?
- Should new, so-called Generation IV, reactors with the ability to use uranium more efficiently, maximise passive and inherent safety, and reduce and recycle nuclear waste, be developed for the UK – as is being done elsewhere in the world?
- Does the UK have a science base that permits the development of new types of reactors and their associated fuel cycles?

This report examines these questions in a state-of-play assessment of the outstanding challenges across the board in nuclear energy, present and future. It acknowledges the excellent work done by existing reports such as those recently published by the Royal Society,³ the House of Lords,⁴ and the ERP Roadmap⁵ and, mindful not to duplicate this work, it sets out to build on it, providing an exhaustive entry point to nuclear energy and helping policy makers and the general public alike to negotiate their way through the myriad associated issues and challenges.



³ Royal Society Science Policy Centre report (2011): 'Fuel cycle stewardship in a nuclear renaissance' Royal Society: London <http://royalsociety.org/policy/projects/nuclear-non-proliferation/report/>

⁴ House of Lords Science and Technology Committee – Third Report (2011): 'Nuclear Research and Development Capabilities' <http://www.publications.parliament.uk/pa/ld201012/ldselect/ldscitech/221/22102.htm>

⁵ Energy Research Partnership (2012): 'UK Nuclear Fission Technology Roadmap: Preliminary Report' <http://www.energyresearchpartnership.org.uk/nucleartechologyroadmap>

The University of Birmingham

Policy Commissions

The Birmingham Policy Commissions bring leading figures from the public service, industry and voluntary/community sectors together with University academics to generate new thinking, contribute towards increasing public understanding, and identify innovative policy solutions around contemporary issues of global, national and civic concern, and of strategic importance for the UK.

The focus of the current Commission – the future of nuclear energy in the UK – is particularly pertinent in the current context where questions about proposed new nuclear power stations, about the UK's ability to meet its carbon targets, energy security, and fuel poverty are high on the national agenda. The Commission's mandate has not been to produce yet another document on the pros and cons of nuclear energy per se, rather to critically examine the present circumstances and prospects in the UK in the light of current government support and policy, and to assess what needs to be done to maximise the chances that this policy is effective in both the short and longer term.

Members of the Commission bring a balance of expertise reflecting both technical and non-technical perspectives in this widely contested area.

- Lord Philip Hunt of Kings Heath (Chair of the Commission; formerly Minister of State, Department of Energy and Climate Change)
- Professor Richard Green (Alan and Sabine Howard Professor of Sustainable Energy Business, Imperial College Business School, Imperial College London)
- Professor Lynne Macaskie (Professor of Applied Microbiology, University of Birmingham)
- Dr Paul Norman (Senior Lecturer in Nuclear Physics, University of Birmingham)
- Richard Rankin (Programme Director, Energy and Environment Directorate, Idaho National Laboratory, USA)
- Stephen Tindale (Climate and Energy Consultant and Associate Fellow, Centre for European Reform, formerly Executive Director of Greenpeace UK)
- Dr John Walls (Lecturer in Environmental Geography, University of Birmingham)

- Professor David Weaver (Honorary Professor, School of Physics and Astronomy, University of Birmingham)
- Simon Webster (Head of Unit, 'Fusion Association Agreements', European Commission (UoB alumnus))
- Professor Andrew Worrall (Technical Authority for Reactors and Fuels, UK National Nuclear Laboratory)

Martin Freer – Professor of Nuclear Physics and Director of the Birmingham Centre of Nuclear Education and Research – has provided the academic lead for the Commission.

Largely comprising members with affiliations to nuclear science, education or research, the Commission is well placed to critically

examine the actions required to effectively develop the nuclear agenda. It has also sought to engage with those who take a pronounced anti-nuclear energy view.

Launched with a debate at the Liberal Democrats Party Conference in September 2011, the Policy Commission ran until June 2012. Building on existing University of Birmingham research, and working with a range of expert contributors, it reviewed relevant research, received contributions from policy makers, practitioners and academics, and took evidence in two one-day workshops, examining issues particularly pertinent to the UK context. In addition, the Commission hosted a public debate midway through its programme to broadly explore major themes emerging from its deliberations.



Focus of the Policy Commission Report

The report is broken down into three sections: this section provides the background and overview of the Commission as well as the main conclusions of the report; Section II provides a summary narrative of key areas facing the UK in terms of re-establishing nuclear energy; and, finally, for those interested in further information, Section III contains a detailed analysis of the areas covered in the report.

The broad conclusions of the Commission are that:

- There are strong arguments for pursuing a programme of building up a new fleet of nuclear reactors. These include the need to reduce greenhouse gas emissions to mitigate climate change and to ensure the UK's energy independence. Nuclear energy may well be the cheapest low carbon energy source. In times of growing domestic energy bills and fuel poverty, reliability and cost are essential. It should be part of an overall programme of developing renewable sources and maximising energy efficiency.
- The future of nuclear new build lies in the balance. Progress in fixing the market conditions that make investment favourable has been slow, and there is a significant danger that the current level of engagement of the utilities will be lost. The financial risks associated with building new nuclear power stations are beyond the balance sheets of many of the utilities. These risks need to be shared between the public and private sectors.
- Considerations in the nuclear sector include not only new build but also the fuel cycle and waste disposal. This sector is highly complex and strategic decisions have both short and long term consequences. These decisions cannot be made by the Government or Industry alone. A coherent long term strategy, or roadmap, is required to ensure that decisions on the nature of the fuel cycle, plutonium stockpile and waste disposal do not close off future options.
- The Government should set up a statutory Nuclear Policy Council, or similar, modelled on the Committee on Climate Change, that can establish and champion a long term, technically informed, roadmap for nuclear energy in the UK.
- The UK has fallen significantly behind its international competitors in fission energy research and now has very few world-leading research facilities. Investment in new facilities (eg, the National Nuclear Laboratory's Phase 3 labs) is required to maintain national expertise in the nuclear fuel cycle, and support for other national facilities (eg, the Dalton Cumbrian Facility) should be funded by the research councils. In view of the UK's current expertise in materials science, it should seek to develop major world-class research facilities based around the development of new materials capable of performing in the more hostile conditions present in Generation IV (and fusion) reactors.
- Geological disposal is the widely and scientifically accepted solution for the safe management of high-level nuclear waste. Identifying the optimal site involves a balance between finding a suitable geology and a community prepared to host the repository. While the UK approach of seeking voluntary host communities is appropriate, the present position of having a single confirmed potential host community in Cumbria is a weakness and more needs to be done to encourage other communities to engage with the siting process. This may involve increased efforts by the implementing organisations in communication and dialogue as well as ensuring that the incentives are set at an appropriate level.
- Public opinion is extremely important for the future of nuclear energy. However, public understanding of nuclear energy, nuclear radiation and the risks associated with nuclear reactors is currently relatively weak. It has been argued that improved understanding of the science behind nuclear energy can help to improve public acceptance.
- There are challenges in ensuring there is a suitably skilled workforce in place for when the build programme commences. Even though much has been achieved already, there are significant concerns that the scale of training achievable will not match demand. Effective government engagement is required to stimulate training and education programmes.



Section II

The fundamental questions

This section examines eight key areas connected with the development of nuclear energy in the UK. These range from the UK's energy policy, hurdles to new build, the nature of the fuel cycle and waste disposal, through to public opinion. A more detailed discussion of the issues, and a glossary of terms, can be found in Section III of the report.

Where is the UK going with energy policy?

Robust evidence exists demonstrating the impact that climate change is already having on the earth, showing with a high degree of certainty that there is a manmade component.⁶

Consequences are dramatic: sea level rises of up to 0.6m are predicted by the end of the 21st century⁷, as are increases in extreme weather and acidification of the sea. Worst for the UK, and its European partners, the Atlantic Meridional Overturning Circulation (AMOC) – the Gulf Stream – is predicted with a 90% confidence level to decrease in strength over the next 100 years.⁸ The Little Ice Age that began in the 16th century was associated with a moderate decline in strength of the AMOC.⁹ So, although average global temperatures are set to rise, the consequence could be a colder Northern Europe.

The Kyoto Protocol agreed in 1997¹⁰ commits nations to cut greenhouse gas emissions by an average of 5% (8% for the then 15 European Union (EU) Member States) relative to 1990 levels over the five-year period to 2012. In an extension of this policy, and in line with EU strategy, the UK made a unilateral commitment to reduce its greenhouse gas emissions (focussing on CO₂) by 80% of 1990 levels by 2050 – a commitment now enshrined in

the 2008 Climate Change Act.¹¹ Some of this reduction may be achievable through energy efficiency measures (eg, the Green Deal¹²), but decarbonisation of electricity generation, heat and transport is the bulk of the solution. The UK's electricity consumption is approximately 350 TWhr per year and the lion's share (approximately 70%) is produced by CO₂-generating coal and gas power stations. The solution then seems obvious: decommission coal and gas power stations and replace them with low carbon alternatives. Until recently, the alternatives have been renewable sources: predominantly bio-energy and wind, with strong recent growth (from a tiny base) in solar power.

Is this a plausible solution? The answer is not trivial. The UK's road transport produces approximately 20%¹³ of CO₂ emissions and electrification of transport would increase electricity demand. History shows that it is unlikely that electricity demand in the UK will plateau or decrease – in the last 30 years there

⁶ <http://www.ipcc.ch/> : <http://srren.ipcc-wg3.de/report>

⁷ Ahlenius, H. (2007): 'Projected sea-level rise for the 21st century' From collection: Global Outlook for Ice and Snow. UNEP/GRID-Arendal http://www.grida.no/graphicslib/detail/projected-sea-level-rise-for-the-21st-century_b9c1#

⁸ Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.) (2007): 'Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change' Cambridge University Press, Cambridge, UK and New York, NY, USA and http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch10s10-3-4.html

⁹ Clark, P. U (2009): 'Abrupt Climate Change: Final Report, Synthesis and Assessment Product 3. 4' Diane Publishing: Darby, PA, USA

¹⁰ United Nations Framework Convention on Climate Change: Kyoto Protocol http://unfccc.int/kyoto_protocol/items/2830.php

¹¹ 2008 Climate Change Act, DECC http://www.decc.gov.uk/en/content/cms/legislation/cc_act_08/cc_act_08.aspx

¹² Green Deal, DECC http://www.decc.gov.uk/en/content/cms/tackling/green_deal/green_deal.aspx

¹³ Centre of excellence for low carbon and fuel cell technologies (Cenex) 'Electrification of Transport Study' (2008): <http://www.cenex.co.uk/research/electrification-of-transport>





has been an approximately linear growth in demand of 3–5TWh/year.¹⁴ Though the recent economic slow-down has bucked this trend, consumption over the longer term is set to rise. One drawback of renewable energy sources is that they need a lot of space: wind turbines have an energy density of 2–3W/m², so that a 25 MW wind farm would need ten square kilometres of land.¹⁵ To put this into context, the UK's demand divided by its land area gives a figure in excess of 1 W/m², implying coverage of 1/3–1/2 of the UK landmass with wind turbines. Offshore wind turbines solve this problem, but create others, not least of which is the increased cost, which is an important consideration not only for the domestic consumer and voter, but also for Industry.

Predicting future electricity prices is complex and depends on the cost of construction, operation (including fuel prices) and decommissioning (and in the case of nuclear, disposal of nuclear waste) and offsetting

measures such as the Carbon Floor Price. Many studies^{16, 17, 18} have examined the cost of electricity production by different generating technologies. Combined cycle gas turbines (CCGTs) are often found to be the cheapest technology (depending on the gas price) as they use exhaust gases from one turbine to make steam for another, improving efficiency and reducing fuel costs. They are less attractive when account is taken of CO₂ emissions, through a carbon tax, or the cost of eventual carbon capture and storage (CCS) technology is included. Coal stations have higher emissions than gas-fired plants, and consequently suffer a higher carbon cost penalty.

Technologies with low carbon emissions (measured over their entire life cycle from construction to decommissioning) include nuclear energy, wind and solar.¹⁹ In part because of their intermittency, wind and (especially) solar power currently have

higher costs than gas, at least if we ignore the latter's carbon costs. Many wind farms are a long way from consumers, requiring additional investment in the transmission system, and back-up capacity is needed when the wind is not blowing. These additional costs must ultimately be borne by the electricity consumers, though they are not always included in cost comparisons with other energy sources.

The view of the Department of Energy and Climate Change is that nuclear energy is a competitive low carbon option for base load electricity generation, and compares favourably with coal and gas if fuel and carbon prices, as expected, rise over time.

In order to achieve CO₂ emissions targets the price of electricity may need to rise substantially. The subsequent potential damage to industrial competitiveness and jobs is forcing many countries to reconsider their commitments to combatting climate change. Moreover, there is a concern that rising energy prices will drive more people into energy poverty. This concern has been reflected in the lack of commitment at the last climate change summit in Durban.²⁰ Nonetheless, to its immense credit, the UK has maintained its commitment to decarbonisation. Furthermore, it considers the solution is likely to involve substantial nuclear new build.

Before focussing on a UK solution, one should examine the options for Europe as whole, especially since commitments are being taken in the frame of European Union (EU) energy and environmental policy, and energy options are increasingly being developed and technologies integrated at the regional, if not global, level. Already in 2007, the EU Council adopted energy goals aiming, in the 2020 timeframe, to reduce EU greenhouse gas emissions by 20%, increase the share of renewable energy to 20% and make a 20% improvement in energy efficiency (the so-called 20/20/20 targets).²¹ More recently, the EU Energy Roadmap 2050 has been developed²² and though for the moment this is not being linked with firm commitments agreed collectively at EU level, it does lay out a number of scenarios for reducing greenhouse gas emissions on a scale and timeframe that



match the UK's decarbonisation plans, ie, at least an 80% reduction in CO₂ emissions below 1990 levels by 2050. In all the EU scenarios there is an increasing role for electricity and renewable energy contributes much more to primary energy consumption – at least 55% by 2050 (cf 10% today). Nuclear would continue to provide an important contribution in those countries having chosen this option, accounting for up to 18% of EU primary energy (cf 14% today), though in other scenarios nuclear remains at today's level or decreases. In this regard, the fact that the roadmap was finalised only after the events at Fukushima undoubtedly had an influence on the way nuclear energy – which is a very politically sensitive issue at the best of times – has been treated. One of the most significant additional factors is energy savings through efficiency, requiring reductions in energy usage of up to around 40% by 2050 depending on the scenario. However, most if not all the EU

Energy Roadmap scenarios require huge technological advances. These include the demonstration that carbon capture and storage can work, the development of smart grids and energy efficient devices and energy storage systems. The clock is ticking and though 2050 is still a long way off, there is no guarantee that all required advances will be scientifically and technically feasible, or that technologies will be proved commercially viable. On the other hand, it can be argued that nuclear energy is an established, proven, technology that can deliver decarbonisation and energy security while retaining EU competitiveness.²³

The Committee on Climate Change examined in detail potential scenarios of how the UK could reach the climate change targets and suggests a range of options. Its 2011 Renewable Energy Review sets out an illustrative scenario '... in which commitments on support for offshore wind and marine through

the 2020s are broadly in line with planned investment and supply chain capacity to 2020. Together with ongoing investment in onshore wind, this would result in a 2030 renewable generation share of around 40% (185 TWh). Sector decarbonisation would then require a **nuclear share of around 40%** and a CCS share of 15%, along with up to 10% of generation from unabated gas.²⁴ It was estimated that this would result in moderate (£50–60 in real terms) increases to annual household bills.

Note 23	2008 CO ₂ emissions per capita excluding land use and forestry (tonnes)	% of nuclear in gross inland energy consumption (2009)	2009 electricity consumption per capita (kWh)	2010 household electricity prices (€-cents/kWh)	2009 GDP per capita in 'purchasing power parity' (EU av.= 100)
EU-27 average	8.17	14	5441	17.1	100
Germany	10.37	11	6043	24.4	117
France	6.04	40	6578	12.9	107
UK	8.53	9	5234	14.5	113

¹⁴ DECC (2010): 'UK Energy in Brief 2010' A National Statistics Publication, DECC: London <http://www.decc.gov.uk/assets/decc/statistics/publications/brief/190-uk-energy-in-brief-2010.pdf>

¹⁵ Mackay, D (2009): 'Sustainable Energy – without the hot air' UIT: Cambridge, UK <http://www.withouthotair.com/>

¹⁶ Royal Academy of Engineering (2004): 'The Cost of Generating Electricity' Study by PB Power. The Royal Academy of Engineering: London http://www.raeng.org.uk/news/publications/list/reports/Cost_of_Generating_Electricity.pdf

¹⁷ Lea, R: (2012): 'Electricity Costs: The folly of Wind-power' Civitas: London <http://www.civitas.org.uk/economy/electricitycosts2012.pdf>

¹⁸ Renewable Energy Foundation (2011): 'Energy Policy and Consumer Hardship' Renewable Energy Foundation: London <http://www.ref.org.uk/attachments/article/243/REF%20on%20Fuel%20Poverty.pdf>

¹⁹ Parliamentary Office of Science and Technology (2006): 'Carbon Footprint of Electricity Generation' POST: London <http://www.parliament.uk/documents/post/postpn268.pdf>

²⁰ United Nations Framework Convention on Climate Change: Durban Climate Change Conference – November/December 2011. http://unfccc.int/meetings/durban_nov_2011/meeting/6245.php

²¹ European Commission: 'European Energy 2020 strategy' http://ec.europa.eu/energy/energy2020/index_en.htm

²² European Commission: 'Energy Roadmap 2050' http://ec.europa.eu/energy/energy2020/roadmap/index_en.htm

²³ Data from 'Energy, transport and environment indicators' Eurostat (European Commission), 2011 Edition – (http://epp.eurostat.ec.europa.eu/portal/page/portal/product_details/publication?p_product_code=KS-DK-11-001) and European Environment Agency – greenhouse gas data viewer (<http://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer>)

²⁴ Committee on Climate Change (2011): 'The Renewable Energy Review' Committee on Climate Change: London <http://www.theccc.org.uk/reports/renewable-energy-review>

The current contribution of nuclear energy to UK electricity generation (15%) is gradually being reduced to zero by 2035 as the existing nuclear power stations reach the end of their lives. If the UK is to remain committed to climate change targets, then many believe that an investment in nuclear energy is required at least at a level consistent with maintaining existing generating capacity and perhaps even increasing this up to 40% of electricity generation. However, even to maintain 15% by 2035, never mind reaching 40%, will require outstanding effectiveness of government policy (eg, in delivering the Electricity Market Reform²⁵) above and beyond the performance to date. Lack of clarity in government energy policy is leading to substantial nervousness in energy markets which may well have contributed to the decision of E.ON and RWE to sell their shares in Horizon Nuclear Power – one of consortia planning to build new nuclear power stations in the UK.²⁶ There is still significant uncertainty as to whether EDF with Centrica will commit to nuclear new build in the UK²⁷ – here the changes to national politics in France could have an impact. Much still lies in the balance and relies on getting the economic conditions for investment right. Here the Electricity Market Reform (EMR) bill is key and further delays in its drafting and implementation could have far-reaching consequences.

An alternative, and certainly less palatable, approach would be to compromise on climate change targets – something already signalled by countries such as Canada.²⁸ The energy mix might then look very different with less emphasis on renewables and an increased focus on CCGT. Indeed, the April 2011 UK budget²⁹ introduced measures to improve the utilities' confidence in gas. The potential significant increase in gas reserves through shale gas exploration has the potential to hold down the international gas price, making it attractive in the short term. The UK shale

gas reserves were recently estimated to be in the top 20 internationally.³⁰ The question, over and above the environmental concerns, is how much gas can be extracted at a cost that makes it worthwhile? Such uncertainties have made the formulation of energy policy problematic; but even if climate change no longer takes centre stage, an overriding concern in energy policy should still be **energy security of supply**. Here again, as an essentially indigenous source, nuclear energy would contribute significantly as part of the UK energy mix.

The lack of certainty and clarity in the UK Government policy on energy, and the hiatus while the EMR bill is drafted and put into law, is producing a *sense of drift* in which energy companies lack the conviction to invest in new plant construction. In part this is a consequence of the deregulation of electricity markets, where Government attempts to create the right economic environment through 'market corrections' or subsidies (eg, Contracts for Difference, the Carbon Floor Price...²⁵) to encourage a particular type of power station to be built, rather than simply fixing the number and type of power stations. This 'weak coupling' between policy and final realisation is a serious cause for concern when it comes to an issue of such national strategic importance. The current model is one in which the market conditions are created and then the Government must trust the utilities to behave as anticipated.



²⁵ DECC: 'Electricity Market Reform (EMR) White Paper 2011' http://www.decc.gov.uk/en/content/cms/legislation/white_papers/emr_wp_2011/emr_wp_2011.aspx

²⁶ BBC News, 29 March 2012: 'RWE and E.ON halt UK nuclear plans at Wylfa and Oldbury' <http://www.bbc.co.uk/news/world-17546420>

²⁷ Peston, R. (2012): 'Is the UK's nuclear future in jeopardy?' BBC News, 29 March 2012 <http://www.bbc.co.uk/news/business-17550282>

²⁸ Black, R. (2011): 'Climate summit sees Canadian strike on Kyoto treaty' BBC News, 28 November 2011 <http://www.bbc.co.uk/news/science-environment-15930562>

²⁹ HM Treasury (2011): 'The Budget Report 2011' The Stationery Office: London http://cdn.hm-treasury.gov.uk/2011budget_complete.pdf

³⁰ Gloystein, H. and Johnson, C. (2012): 'Exclusive – UK has vast shale gas reserves, geologists say' Reuters, April 17th 2012 <http://uk.reuters.com/article/2012/04/17/uk-britain-shale-reserves-idUKBRE83G0KS20120417>



Conclusions and Recommendations

- It can be argued that a free market approach to energy delivers value for money for the consumer through competition. There is, however, a danger that this could lead to undue concentration on keeping short term costs down and fail to consider longer term issues, ultimately leading to higher costs.
- Deregulation of the energy markets has weakened the Government's ability to determine the UK's energy mix. While some past government decisions have been clearly unsuccessful, the ambitions of privately owned companies will not always align with UK national interests. Creating the right market conditions will not necessarily produce the right result.
- The Government needs to articulate a more coherent policy on energy, which sets out the medium and long-term energy mix to support economic development, energy security and emissions reduction. The Electricity Market Reform²⁵ package can help, but more information on its details is urgently required.
- The scale of nuclear new build needs to be clarified – is nuclear energy to provide 15% or 40% of the UK's electricity? If climate change targets are to be met through nuclear new build, then greater urgency is required.
- The government should create a statutory Nuclear Policy Council, or similar, modelled on the Committee on Climate Change, to provide a long term framework to deliver the national strategy in nuclear energy and oversee progress along an agreed roadmap.



What is the immediate future for nuclear energy?

Will new build happen in the UK?

Though nuclear energy remains an attractive option, there are critical hurdles to be overcome.

These include ensuring that the electricity market reform strikes the right balance to give utilities sufficient confidence to invest in new build, ensuring the right project management principles are in place so that construction is to time and budget, ensuring there is an established and suitably tooled UK supply chain and, finally, that there is a well qualified workforce in place on a timescale that matches the build programme.

Generic Design Assessment and Licensing

A pre-requisite for new nuclear power stations such as the EPR and AP1000 is that the Secretary of State has to issue a Regulatory Justification under the UK's laws on activities involving radiation – this is equally true for any new class or type of practice that involves radiation, where the case has to be shown that the benefits outweigh the detriments. This process was completed in October 2010.

In addition, nuclear safety regulators (the Health and Safety Executive's Office for Nuclear Regulation and the Environment Agency) have been conducting a Generic Design Assessment (GDA) for each of the new designs in order to assess general acceptability before suitability for a particular site is considered in the planning process. The GDA approach and a 'pre-licensing' assessment of technologies were introduced specifically for new nuclear build to not only

streamline the process but also provide greater transparency and clarity for the requesting parties and all other stakeholders, including the public; they have been successful in their implementation and objectives. Four companies submitted designs for assessment under GDA in July 2007: in addition to the Advanced Passive Reactor from Westinghouse (AP1000) and European PWR from Areva (EPR), proposals were submitted by Atomic Energy of Canada Limited (AECL) and GE-Hitachi Nuclear Energy. The GDA process started with a high-level assessment, which all four designs passed, but AECL withdrew its design before work started on the next, more detailed, stage. GE-Hitachi suspended their application a few months later. None of the current consortia proposing new stations in the UK (see below) are planning to build either type of plant.

The GDA process is iterative, both in the sense that the regulators start with an overview of the reactor designs and then consider more detailed issues of system design and evidence for safety, and in the sense that the companies are given opportunities to respond to the regulators' concerns. Both the AP1000 and EPR reactor designs have been given interim design acceptance. Some issues are still to be addressed, but the regulators were satisfied with the companies' approaches to resolving these outstanding problems.

Overall, the process of gaining government and regulatory approval for building new nuclear power stations in the UK appears to be close to completion and is an example of best practice. An independent assessment of the GDA process has recently been published.³¹

Decision to Build

Three consortia have shown an interest in building new nuclear power stations in the UK. EDF Energy has set up a consortium with Centrica (the owner of British Gas) to build new stations; the two companies also share ownership of most of the UK's existing nuclear stations, through British Energy. Two subsidiaries of German companies, E.ON UK and RWE npower, set up Horizon Nuclear Power. Both parent companies operate nuclear reactors in Germany, but not in the UK. A third consortium, NuGen, brought together Iberdrola (owner of Scottish Power), GDF Suez and Scottish and Southern Energy. Iberdrola and GDF Suez operate reactors in Spain and Belgium respectively.

Scottish and Southern pulled out of the NuGen consortium in September 2011. Its stake was bought by its partners, Iberdrola and GDF Suez, which now each own 50% of the consortium. RWE and E.ON announced in March 2012 that they had decided to sell Horizon Nuclear Power, which had plans to develop two nuclear sites in the UK – it remains to be seen if other investors will step in. RWE's press statement explicitly linked the decision to the German nuclear phase-out, the company responding by divesting assets and reducing its capital expenditure. In April 2012, the *Financial Times* reported that Centrica had told the Government that it was likely to withdraw from the consortium with EDF Energy unless it received assurances on the future price of nuclear electricity.

The construction of nuclear power stations is capital intensive requiring billions of pounds of investment. Energy utilities must have reasonable prospects of making a return on this investment in the long term, and be compensated for the risks involved. In the current economic climate, the challenge is not simply predicting lifetime economics but also how to raise the billions needed up front.

To reduce the risks for low carbon generators the UK Government plans to intervene in the electricity market, introducing a 'feed-in tariff' with a 'contract for difference' (FiT with CfD²⁵). This has the potential to fix a nuclear station's revenues at a level sufficient to cover its costs, regardless of swings in the wholesale price of power. The FiTs used for renewable power in Europe pay a set price for all the output from a station, giving it no incentive to respond to market signals, for example by scheduling maintenance at times of relatively low demand. The proposed arrangements for nuclear energy aim to preserve some market signals, since stations will still have to sell their output into the wholesale market and receive a price reflecting the market value at the time of the sale. In the case of nuclear stations, this market price is likely to be the price for a year's continuous supply of power sold shortly before the start of the year. The CfD part of the arrangement ensures that the station will also receive, or make, additional payments based on the difference between a strike price specified in the contract and the market price for the kind of power the station is selling – how this is measured will also need to be specified in the contract. In any event, the station still has to find a buyer for its power and operate in a way that customers want, but as long as it can sell at close to the market price, the sum of the revenues from the sale plus the additional payments should be nearly constant.

The consortia will not be willing to take a final investment decision to build a new station (and may be reluctant to spend much money preparing to do so) until they know exactly how these contracts will work. For example, it is not yet clear who the counter-party to the contracts will be (possibly the National Grid) and how their finances will be guaranteed, and in addition since these contracts will ultimately be financed by electricity consumers through the electricity price, watertight arrangements are needed to ensure that revenues are passed on to nuclear owner/operators.

□ **The Government should clarify the terms of the FiT-CfD contracts as soon as possible, and put in place robust arrangements to make them acceptable to the parties investing in new build.**

In the absence of recent experience in the UK, which would enable more accurate cost estimates to be made, the risks associated with a 'first of a kind' (FOAK) nuclear plant are particularly high. Gas-fired power stations can be project financed – the parent company (or joint venture) sets up a subsidiary to build and run the station, financed with a mix of debt and equity put in by the parent(s). If the project is risky, the proportion of equity and the interest rate on the debt will be higher than if the project is regarded as safe.

For nuclear power stations, it would be better to minimise the cost of capital since this is the biggest financial hurdle – even if this means reducing the incentive for the utility to bring down the construction cost. Minimising the cost of capital can be achieved by linking the final price of electricity under the FiT with CfD to the cost of building the station, for example through an open-book approach to contracting, in which the contract price is directly linked to the actual costs, rather than attempting to fix a price that would inevitably include a high margin for error. The contracts should not ignore incentives – there should be modest payments for keeping to time and budget – but it is important to recall that real incentives are generally linked to risks.

Project Management

Owing to the complexity of the construction of large scale projects, a realistic determination of the construction costs is challenging, especially for a FOAK project. Moreover, the nuclear industry does not have a good track record in terms of keeping projects within cost. In recent times the EDF EPR reactor at Flamanville, France, has seen costs rise at an annual rate 13% above Eurozone inflation.³² The construction of the Olkiluoto 3 power plant in Finland has also encountered significant delays – it was due to be completed in 2009, but now is not expected to start operation until 2014. In addition, in the UK, the Nuclear Decommissioning Authority's (NDA) estimates of the cost of decommissioning existing facilities have risen from £47.9bn in 2002 to £103.9bn in 2011, corresponding to a rate 4.2–6.0% above inflation.³³ This raises the concern that new nuclear projects could spiral out of control requiring significant public subsidy. This in part led to the establishment of the Generic Design Assessment.

EPRs of a similar design to those in France and Finland are being built in China at Taishan. These were started in 2009 and 2010 and construction is on course to be much faster and cheaper than the Finnish and French experience^{34, 35}. Similarly, construction of the AP1000 design reactors in China is also on schedule.³⁶ The successful project management developed for these projects needs to be transferred to the UK new build programme. The new plant construction experience in Korea is also seen as a model for what can be achieved elsewhere.³⁷

The most recent large scale construction project in the UK has been the London Olympics. The cost of the construction of the Olympic stadium is close to £500m and the total cost including the other venues is £1bn. This was completed to budget and on time with a very good safety record and shows that successful civil engineering projects can be managed in the UK. Nuclear build, however, is an order of magnitude higher in terms of cost, complexity and regulatory control.

□ **The success of any major new build programme relies on the completion of the first reactor (likely to be at Hinkley Point) on time and within budget and with high levels of local engagement. This has to be followed by learning from experience from the FOAK construction, resulting in faster and less expensive construction – a fleet of reactors of the same design is the only way to achieve this. If the construction of the first reactor is a failure then the downturn in public support could see the premature termination of the entire programme. It is essential that lessons are learned from the construction of other similar reactors worldwide (eg, China and South Korea) and experienced project management is engaged.**

Supply Chain

It is estimated that the construction of new nuclear power stations in the UK will require an investment of the order of £40bn by 2025.³⁸ There are tremendous opportunities

for UK business to engage in the construction and the associated supply chain, stimulating employment across the construction and engineering sectors. The Nuclear Industry Association 2006 report³⁹ (updated in 2008⁴⁰) concluded that it should be possible for the UK to supply 70% of the components of a new nuclear plant. Further, it was believed that this could be increased to 80% with appropriate investment in manufacturing facilities. It was recognised by the NIA that, due to the lack of domestic capability, large components such as the reactor pressure vessel and steam turbines could not be constructed in the UK and would need to be imported. At the 70% level this would imply that 'on the basis of a capital cost of £2m per MWe, UK orders worth more than £4,500m could conceivably be available for a twin unit EPR, and £3,500m for a twin unit AP1000.'³⁸ A programme of 10 reactors would generate 64,000 person-years of employment.³⁸

³¹ Shared Practice – Current and recent projects <http://www.sharedpractice.org.uk/Projects/projects.html#nuclear>

³² EDF Investor Statements (2005–2011): <http://shareholders-and-investors.edf.com/news-and-publications/annual-reports-42724.html>

³³ Extracted from DTI and NDA reports(2002–2011): <http://www.greenpeace.org.uk/sites/files/gpuk/FUP-Subsidy-Report-Mar2011.pdf>

³⁴ World Nuclear News (18 April 2012): 'Landmarks for new Chinese nuclear plants' http://www.world-nuclear-news.org/NN-Landmarks_for_new_Chinese_nuclear_plants_1804124.html

³⁵ Energy Business iQ (Apr 17, 2012): 'AREVA delivers EPR reactor components to Taishan nuclear power plant' <http://nuclear-power.energybusinessiq.com/news/display.aspx?title=AREVA-delivers-EPR-reactor-components-to-Taishan-nuclear-power-plant-12647>

³⁶ World Nuclear News (04 May 2011): 'Chinese nuclear construction continues apace' http://www.world-nuclear-news.org/NN-Chinese_nuclear_construction_continues_apace-0405115.html

³⁷ Matzie, R. A. (2005) 'Building New Nuclear Plants to Cost and Schedule – An International Perspective' Nuclear Fission Seminar, Westinghouse Electric Company and BNFL http://www.raeng.org.uk/societygov/policy/current_issues/energy/pdf/energyseminars/Regis_Matzie.pdf

³⁸ Nuclear Industry Association (NIA): 'Nuclear Business Opportunities' <http://www.nuclearsupplychain.com/component/content/article/65>

³⁹ Nuclear Industry Association (NIA) (2006): 'The UK capability to deliver a new nuclear build programme' Nuclear Industry Association: London http://www.niauk.org/images/stories/pdfs/MAIN_REPORT_12_march.pdf

⁴⁰ Nuclear Industry Association (NIA) (2008): 'The UK capability to deliver a new nuclear build programme. 2008 Update' Nuclear Industry Association: London <http://www.niauk.org/images/stories/pdfs/supplement%20for%20web.pdf>





The imperative for domestic, UK, engagement comes from the need for a substantial component of the build programme to be UK-based so that the economic benefit is felt – it would be a wasted opportunity if most of the funding were to go to overseas suppliers. There is also the significant potential to develop export opportunities. As an example, Sheffield Forgemasters, a heavy engineering firm based in Sheffield, has already won contracts to supply components for the AP1000 in China.⁴¹ **In this regard the work of the Nuclear Industry Association in promoting UK industry and facilitating engagement has been excellent.**

However, there also exist potential pitfalls. In building new nuclear power stations, it takes approximately five years to get to the point of construction and a further five years to complete construction. The initial period includes licensing and the present Electricity Market Reform (EMR) process. Internal investment by companies to develop new facilities and skills requires certainty. Currently, there is very little certainty in this sector and the building of nuclear power stations, though likely, is not guaranteed. Hence, there will be a natural reluctance for companies lower down the supply chain to engage strongly. As a carrot, the recent Technology Strategy Board (TSB) call⁴² to provide funding to develop the nuclear power supply chain (which includes decommissioning) is designed to improve businesses 'competitiveness, productivity and performance in the nuclear sector' and provides, through funding from the NDA, TSB, Engineering and Physical Sciences Research Council (EPSRC) and Department of Energy and Climate Change (DECC), mechanisms for SMEs (small/medium-sized enterprises) to engage. **This is a £15m programme, and should be the first of several such steps to developing the UK skills base.**

It is noteworthy that EDF proposes to develop the Hinkley Point and Penly (in France) EPRs together, with common procurement arrangements during construction.⁴³ The danger is that a significant fraction of the supply chain for both projects will be located in France.



Recommendations:

- **For businesses to engage strongly and more widely with the opportunities in UK new build, certainty is required. Incentive schemes such as those offered by the TSB are needed to encourage SMEs to prepare for the opportunities in advance.**
- **The UK Government should ensure as part of the negotiations with the new build companies that the opportunities for UK business to engage in the new reactor build programme are maximised.**

In 2008 Sheffield Forgemasters was planning to extend its capacity to include very large forgings (construction of large components) for the nuclear new build programme, making it one of only two companies in the world with such capabilities. An £80m government loan was sought, and though this was initially awarded shortly before the 2010 election, it was subsequently withdrawn by the new Coalition Government⁴⁴ Nonetheless, in 2011 a loan of £36m was provided by the Government to support smaller scale equipment investment,⁴⁵ the justification being that post-Fukushima the global demand for new nuclear construction would decline. But once again this is an example where a short term approach has potentially resulted in a lost opportunity for the UK on the world stage.

Recommendation:

- **The fact that the nuclear new build programme in the UK is likely to be in advance of those in other countries means there exists potential for UK companies to place themselves in a strong position in terms of international supply chains and exports. This opportunity should be maximised. The Government can support this through loans to key companies.**

Skills and Education

New nuclear build will test the UK supply chain and skills base. It is estimated that employment in manufacture, construction and operation of a twin-unit station will be 21,200 person years over the six-year period of construction and commissioning,⁴⁶ with peak numbers of 12,000 for construction, 5,000 for operations and 1,000 in manufacture to deliver a 16 GWe fleet

by 2025. Aside from the scale of workforce required, the level of regulation and required safety awareness is significantly above those in other fields of construction and operation. This places additional constraints on training for the nuclear new build. A series of reports by Cogent – the UK's industry skills body – have provided the necessary focus on this problem,⁴⁷ highlighting the key concern over skills in areas such as project management, geotechnical engineering, safety case authoring, non-destructive engineering, high integrity welding, manufacturing engineering (mechanical electrical, production, chemicals), control and instrumentation, design engineering (mechanical, electrical, production, chemical), planners and estimators and regulation.

Amongst a series of Cogent recommendations is the development of a range of foundation programmes, apprenticeships and approaches to reinforce the Nuclear Passport scheme, a system offering all nuclear organisations instant secure Web access to information on the nuclear skills base, and a detailed overview of the training completed by their workforce as well as contracting organisations.⁴⁸ In parallel, there have been efforts to address the key skills and training challenges. The National Skills Academy Nuclear (NSAN)⁴⁹ was established to address these challenges facing the nuclear industry by ensuring it has a skilled workforce and supporting the Nuclear Passport programme, and Cogent's Nuclear Island⁵⁰ civil engineering project has been developed to stimulate the Higher Education (HE) sector in collaboration with Imperial College and the

Constructionarium.⁵¹ The latter is presently being broadened to include electrical and mechanical engineering skills.

Participation of students in such hands-on training programmes has been funded through support from, for example, civil engineering contractors. Whilst companies with a long tradition of working in the nuclear sector have financially supported educational programmes (such as the University of Birmingham's 'Physics and Technology of Nuclear Reactors' Masters course), there has been a reluctance especially in the civil and manufacturing sectors to actively engage in funding national training programmes in advance of the commencement of construction of new nuclear stations. Uncertainty in national policy is not helping in this regard. Further, the independent path followed by EDF, investing in Bridgwater College⁵² for example, has led to some fragmentation of the national strategy. There is a significant danger that the skills required for new build will not materialise owing to this uncertainty.

Recommendation:

- **Appropriate funding of educational programmes from Further to Higher Education (FE, HE) is an issue avoided by research councils and Government for some time. Consideration should be given to interim joint Government-Industry funding of educational and training programmes across the sector (FE and HE) to increase the likelihood that there will be an appropriate number of suitably qualified students and workers when new build commences.**

⁴¹ Sheffield Forgemasters International: 'Forgemasters ship first nuclear power component to China' <http://www.sheffieldforgemasters.com/news/2009/08/forgemasters-ships-first-nuclear-power-component-to-china>

⁴² Technology Strategy Board: 'Developing the civil nuclear power supply chain' <http://www.innovateuk.org/content/competition/developing-the-civil-nuclear-power-supply-chain.aspx>

⁴³ Nuclear Industry Association (NIA) (2011): 'The Essential Guide to the New Build Nuclear Supply Chain' Nuclear Industry Association: London http://www.nuclearsupplychain.com/images/stories/pdfs/EGUIDE_Feb_11/essential_guide_final.pdf

⁴⁴ BBC News, 17 June 2010: 'Sheffield Forgemasters' £80m nuclear parts loan axed' <http://www.bbc.co.uk/news/10341119>

⁴⁵ BBC News, 31 October 2011: 'Sheffield Forgemasters gets up to £36m from government' <http://www.bbc.co.uk/news/uk-england-south-yorkshire-15521707>

⁴⁶ Cogent (2010): 'Renaissance Nuclear Skills Series: 2. Next Generation Skills for New Build Nuclear' Cogent SSC Ltd.: Cheshire <http://www.cogent-ssc.com/research/Publications/Renaissance2.pdf>

⁴⁷ Cogent: Nuclear Research – Renaissance Nuclear Skills Series <http://www.cogent-ssc.com/research/nuclearresearch.php>

⁴⁸ National Skills Academy Nuclear: Nuclear Skills Passport <http://www.nuclearskillspassport.co.uk/about>

⁴⁹ National Skills Academy Nuclear <http://www.nuclear.nsacademy.co.uk/>

⁵⁰ Cogent: Nuclear Island http://www.cogent-ssc.com/Higher_level_skills/ni_index.php

⁵¹ The Constructionarium <http://www.constructionarium.co.uk/>

⁵² EDF Energy Hinkley Point (24 January 2011): 'Secretary of State for Energy and Climate Change visits Hinkley Point and opens new Energy Skills Centre' <http://hinkleypoint.edfenergyconsultation.info/newsroom-faqs/press-releases/959>

Is nuclear fission energy a bridging technology?

Currently available nuclear technology has much to offer as regards reducing reliance on imports of gas, limiting CO₂ emissions, and keeping down electricity prices. But is this technology just a stopgap? Are other options likely to emerge in the coming decades?

Fusion energy promises an inherently safe and low waste source of energy, with an almost limitless and ready supply of fuel. The UK is heavily engaged, with EU partners through the Euratom programme, in research on magnetically confined fusion, the Joint European Torus (JET)⁵³ facility at Culham near Oxford being the world's largest research facility. The next step to fusion power is the construction of ITER⁵⁴ in Southern France at a cost of approximately £13bn,⁵⁵ almost half provided by the EU through the Euratom programme. However, though ITER will study fusion plasmas on a scale required in a future power plant, it remains a research project and will not produce any electricity. This will require a further step – DEMO – which if all goes well could deliver power into the grid from 2040 onwards, although the technology would still not be deployable on a commercial scale. Fusion energy remains a challenge, and in particular there is still much to accomplish regarding the development of the technology needed for actual power plants. One of the most critical issues concerns the structural

materials – the large power fluxes, high operating temperatures and the very energetic (14 MeV) neutrons from the fusion process constitute a veritable R&D challenge for materials scientists. New steels, alloys and composite materials are being developed and studied, but this process takes time and samples need to be qualified under irradiations and temperatures equivalent to those in future fusion power plants, requiring dedicated materials testing facilities.

Similarly, it is currently difficult to envisage a future step change in renewable technologies such as **wind, wave and solar** that would enable them to provide the complete energy solution, certainly in a scenario of increased electricity demand. It is possible that a combination of **micro-generation** and **energy saving technologies** may re-sculpt the energy landscape, but the overall impact is far from certain. Moreover, the national and international reserves of **gas** on these timescales are expected to be depleted.⁵⁶

⁵³ The Joint European Torus (JET): <http://www.efda.org/jet>

⁵⁴ ITER: <http://www.iter.org>

⁵⁵ McGrath, M (2010): 'Deal finalised on fusion reactor' BBC News 29 July 2010 <http://www.bbc.co.uk/news/science-environment-10793883>

⁵⁶ RWE: 'Deposits and extraction of Natural Gas' <http://www.rwe.cz/en/deposits-of-natural-gas>



So is nuclear fission the future? Fission faces its own resource problems. A little over 60% of the known recoverable resources of uranium are found in four countries – Australia, Canada, Kazakhstan and Russia – with Australia accounting for the lion's share. At current rate of use, these known resources would run out in around 80 years from now,⁵⁷ though as the price rises it may be economic to extract uranium from currently untapped deposits. However, there is an alternative to the costly development of new mining exploitations and/or extraction of lower grade ore bodies, with the associated environmental impact this would cause. Uranium is naturally found in the form of two isotopes, ²³⁸U (99.3%) and ²³⁵U (0.7%), ²³⁵U being the only naturally occurring fissile material (ie, capable of sustaining a nuclear chain reaction). It is this isotope that is enriched and used in current fission reactors – reactor grade enrichments typically being of the order of 4–5%, though in MOX (mixed oxide) fuel roughly the same effect can be obtained by mixing natural (or even depleted) uranium with fissile plutonium (²³⁹Pu) from the recycling (reprocessing) of irradiated fuel from current reactors. Crucially, this 'breeding' of fissile ²³⁹Pu through nuclear transmutation of ²³⁸U can be greatly enhanced in so-called fast reactors, so much so that more new fissile material can be bred than is consumed in the original fuel, meaning that natural or even depleted uranium in the original feedstock can all be converted to fissile material. As a result, existing uranium resources could be made to last 50–100 times longer – thousands of years rather than tens. **There are enough uranium 'tails' (²³⁸U 'residues' from the enrichment process) in the UK to fuel a new build fleet of several tens of GWe of fast reactors for their entire design lifetime, ie, the UK already has sufficient fuel stocks for future**

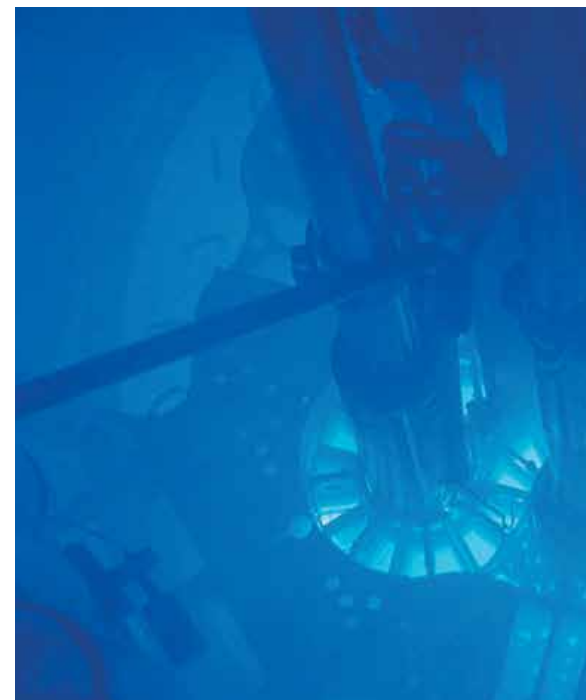
fast reactors without the need to buy any more uranium or to carry out further mining. However, a fissile 'driver' fuel is required to kick-start the process, and this is where the UK's historic plutonium stocks could be used.

More broadly, the suite of future generation reactors known as Gen-IV (Generation IV), which includes both high temperature thermal as well as fast reactors, are aimed at bringing about a revolution as regards sustainability and possible applications of nuclear energy. Apart from the ability to greatly extend the sustainability of uranium resources, Gen-IV plants will demonstrate enhanced proliferation resistance, high levels of safety at least comparable with the latest Generation-III plants (eg, EPR and AP1000) especially as regards passive and inherent safety features, the ability to recycle and eliminate though nuclear transmutation long-lived wastes (so-called minor actinides), thereby greatly facilitating use of future geological disposal facilities, and co-generation of electricity and heat for a range of industrial processes (eg, hydrogen production).

Though potential benefits are significant, so are the scientific and technical challenges – for example, the materials issues confronting fusion power plants are also crucial for certain types of Gen-IV concepts, pointing to important synergies in the research effort. To address these challenges, a large international community has grown up around the Generation IV International Forum (GIF)⁵⁸ – an initiative bringing together nine of the world's major civil nuclear power nations, together with Euratom representing the EU, in collaborative pre-commercial research on a range of Gen-IV concepts. However, the UK

is involved only indirectly through the Euratom Framework Programme,⁵⁹ which is further indication of the UK's current low ambitions and reduced capabilities in related R&D. The size of the fission research community, both academic and industrial, coupled with the level of research funding, places the UK behind most of our European neighbours. Even countries like Italy and Australia, who have no operating nuclear plants, devote a greater fraction of their national energy research budget to fission and radiation protection research than the UK.

In view of the potentially significant contribution of Gen-IV reactors on the 2040+ timescale, and the active involvement of countries like Canada, China, France, Japan, Korea,



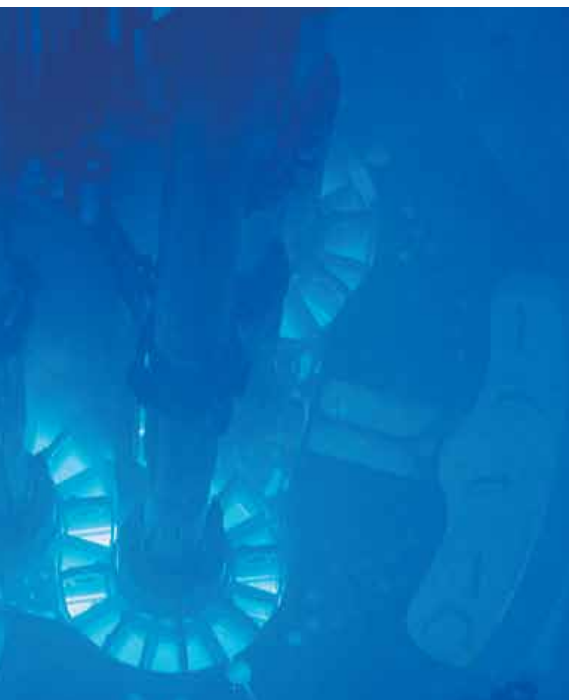
Courtesy of Idaho National Laboratory

⁵⁷ World Nuclear Association (2011): 'Supply of Uranium' <http://www.world-nuclear.org/info/inf75.html>

⁵⁸ Generation IV International Forum (GIF): <http://www.gen-4.org>

⁵⁹ European Commission: The European Atomic Energy Community (EURATOM) http://ec.europa.eu/energy/nuclear/euratom/euratom_en.htm

Russia and USA, in particular through the GIF, there are strong arguments for a re-appraisal of UK research budgets with an aim to promote increased capacity in fission R&D with significant emphasis on Gen-IV research of relevance to, and a priority for, the UK. In particular, this would point to a focus on materials research and gas-cooled reactors – as recommended in the House of Lords report⁴ – but also fast reactor technologies. In turn, this would provide an entry ticket for the UK to collaborate on a win-win basis in its rightful place as part of the international research community.



Conclusions and Recommendations

- **Given the status of present day technologies and long term trends in energy demand, it is likely that nuclear fission will still have a role to play well into the 22nd century and that the reactors of choice in the future will be associated with Generation IV technology. Correspondingly, the UK should engage much more strongly in GIF and should consider becoming an active member, undertaking research where appropriate and in the long term national interest. To this end the UK needs to establish its own R&D projects with a level of funding commensurate with being an active member. It is highly likely that the sodium-cooled fast reactors (SFR) will be the global advanced technology of choice and involvement in associated research programmes should be a priority. Given the national experience in gas-cooled reactors, engagement in research programmes such as the very high temperature reactor (VHTR) is also advisable.**





What has happened to the UK R&D capability?

The UK used to be a world leader in the development of fission technologies, with an R&D workforce in excess of 8,000 and an annual R&D budget of over £300m/year in the 1980s.⁴ At present the human capacity is less than 600 and funding less than 10% of the historical level.⁴

This is significantly below that found in comparable countries, and for a nation with a stated ambition in nuclear energy there is serious concern that the capacity is sub-critical. Once again, this is a powerful argument for reinforcing the UK nuclear R&D budgets to better reflect the strategic importance of the sector.

A subcritical research community, especially within universities and colleges, affects the UK's ability to deliver the high quality specialised educational and training courses that in turn generate suitably qualified young people for the nuclear industry and future research programmes.

Furthermore, the availability of world-class research facilities is of paramount importance if the UK is to contribute to international research programmes and attract the best young researchers into the field. In former times, the UK had a range of such facilities, including the materials research reactors DIDO and PLUTO⁶⁰ at the Harwell campus. These were closed and decommissioned in the 1990s

and the UK currently has few world-class nuclear R&D facilities in operation. There is, however, potential presently being under-exploited. In particular, the UK National Nuclear Laboratory's Central Laboratory has world-leading hot-lab facilities including what is called 'Phase 2', which is presently being commissioned and will permit plutonium research, important for the fuel cycle, to be performed. Its Phase 3 laboratories would permit research with highly active materials in a flexible 'plug and play' user environment, which is extremely novel when compared to other international facilities. However, the facilities are yet to be commissioned – the impediment being that they have to be operated on a commercial basis as a result of NNL's commercial rather than true 'National Laboratory' status. Clearly such facilities would permit a growth in world-leading UK research on the fuel cycle, and there are strong grounds for supporting the commissioning of the Phase 3 laboratories as a user facility as part of the national research infrastructure and with an appropriate funding model.

⁶⁰ United Kingdom Atomic Energy Authority (UKAEA) 'Harwell project profiles: DIDO and PLUTO Material Testing Reactors' <http://www.research-sites.com/UserFiles/File/publications/project-info/Harwell-dido-pluto.pdf>

Secondly, the Dalton Cumbrian Facility will permit the UK to redevelop its irradiated materials and radiation chemistry research capacity. This facility is jointly funded by the NDA and the University of Manchester and is primarily an ion-irradiation facility for materials characterisation, ie, understanding how reactor materials degrade when irradiated. It is currently under construction and the research community is growing. However, its longer-term future needs to be secured and mechanisms for resourcing the operating costs developed.

Working with European Union partners, in particular through initiatives such as the Sustainable Nuclear Energy Technology Platform and under collaborative projects co-funded by the EU's Euratom Framework Programme, UK organisations should fully exploit the potential to share research facilities and to facilitate mutual access. UK support for 'home-grown' research infrastructures should also be commensurate with a policy to maximise complementarity in Europe and ensure critical mass at key centres of excellence, thereby avoiding unnecessary duplication. The bottom line is that if the UK is to stay abreast of developments in advanced nuclear technology, it must develop and/or have access to world-leading research capabilities in areas such as Gen-IV technologies. One promising possibility for specialisation in the UK would be to focus on the development and characterisation of advanced materials, which would enable alignment of crucial research efforts in both Gen-IV and the fusion energy programme.



⁵⁷ World Nuclear Association (2011): 'Supply of Uranium' <http://www.world-nuclear.org/info/inf75.html>

⁵⁸ Generation IV International Forum (GIF): <http://www.gen-4.org>

⁵⁹ European Commission: The European Atomic Energy Community (EURATOM) http://ec.europa.eu/energy/nuclear/euratom/euratom_en.htm



Conclusions and Recommendations

- **Current levels of fission research and related funding are at a subcritical level. In order to regenerate international leadership, investment in research facilities is required as part of a coordinated strategy with European partners. This should be in the form of research council funding for the UK NNL's Central Laboratory Phase 3 development and support for the operating costs of the Dalton Cumbria Facility.**
- **Development of world-class nuclear research capabilities should be a national priority. Materials research, involving both nuclear fuel post-irradiation examination and characterisation (fission) and development of advanced structural materials (fusion and fission), is a critical area for advanced nuclear technology in general, and the solid basis of UK expertise in these fundamental fields would benefit considerably from enhanced national support.**



Is there a roadmap for nuclear?

What about the future fuel cycle and plutonium stockpile?

Joined-up thinking is paramount in ensuring that current investment is not wasted and future investment is not misguided. A clear strategy on long term commitments to nuclear fission research is part of this. How, for example, should the UK best place itself to make an impact in Gen-IV research programmes? A more pressing concern is what the nature of the future fuel cycle should be and what should be done with the plutonium stockpile.

As a result of choosing different reactor types and fuel cycle options over the years, the UK now finds itself with a variety of materials, waste products and spent fuel, each presenting its own challenges and requiring different facilities and processing and handling needs. A standardisation of reactor and fuel cycle options in the future should dramatically reduce the number of facilities required and thereby the operation and maintenance overheads as well as decommissioning costs associated with new build options, whether that is direct disposal or reprocessing following disposal of the resulting residues.

The UK has also developed a number of technologies over the years associated with the fuel cycle. MOX (mixed oxide) fuel is composed of depleted or natural uranium mixed with recycled plutonium from the reprocessing of spent fuel, which then acts as the principal fissile component instead of the ^{235}U in ordinary fuel. The Sellafield MOX Plant (SMP) – the UK's MOX processing plant – was closed in 2011, mainly due because it was no longer commercially viable. At the time it was producing MOX fuel for Japan and Europe and the loss of Japanese orders post-Fukushima exacerbated its commercial challenges.

However, the UK currently has a stockpile of plutonium amounting to approximately 112 tonnes (including 28 tonnes stored for overseas customers – eg, Japan), resulting from the reprocessing of Magnox and AGR spent fuel and PWR spent fuel from overseas. The Government's current preferred option for management of this stockpile is reuse as MOX fuel. However, with the closure of SMP the UK no longer has the capacity to produce MOX, which could have been destined for the new build PWRs such as AP1000 and EPR, both of which can readily use MOX fuel. The Royal Society's report on 'Fuel Cycle Stewardship in a Nuclear Renaissance'³ suggests the construction of a new MOX plant and the use of MOX in thermal light water reactors (the only proven large scale method to deal with the Pu stockpile – which can be regarded as a potential proliferation hazard). Furthermore, in order to minimise the attrition of skills and knowledge, it is important that construction takes place sooner rather than later.

In this regard, both the Generic Design Assessment (GDA) and the Regulatory Justifications of Practices Involving Ionising Radiation for the EPR and AP1000



reactors explicitly exclude the consideration of MOX type fuels for these reactors. As a consequence, a new cycle of licensing and plant modifications will be required if MOX is to be the chosen route for the UK's plutonium stocks, resulting in further delays, risk and costs. It is a moot point whether this should be considered streamlining of the licensing process or lack of foresight.

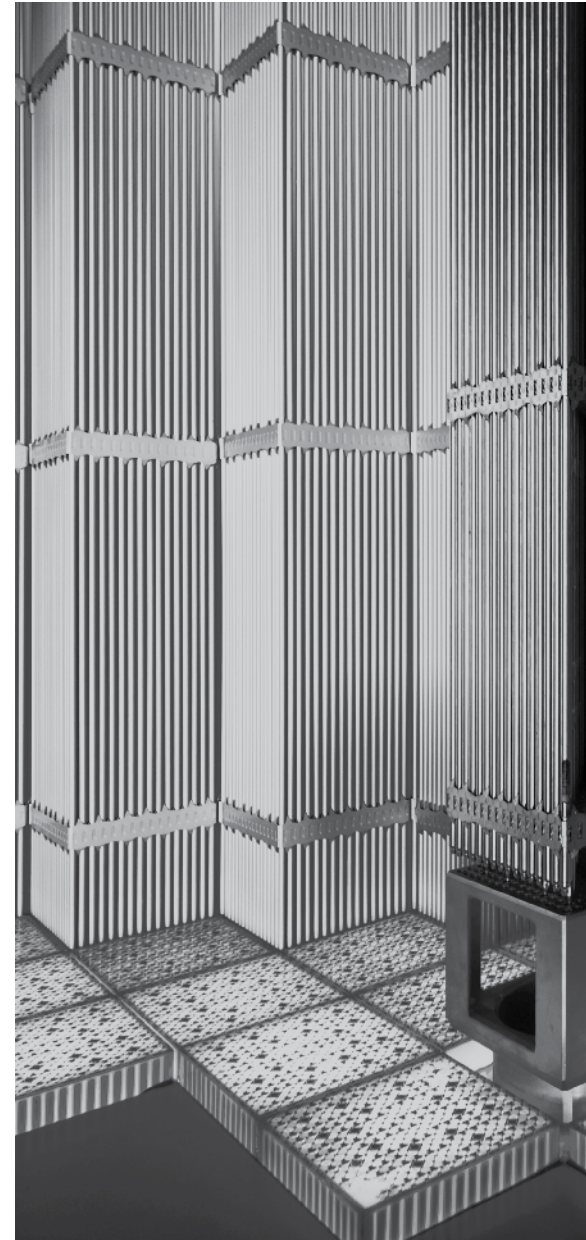
The waters have been further muddied by the GE-Hitachi PRISM reactor.⁶¹ The NDA recently agreed with GE-Hitachi to further study the possible use of a suite of PRISM fast reactors for dedicated plutonium burning.⁶² The NDA had previously concluded that such a technology was not likely to be available within the timescales necessary for disposition of UK plutonium. However this is now being tested by a review to establish whether the design is licensable in the UK and whether any utility will credibly adopt it.

A clear position on the UK policy on plutonium reuse/disposal is required in order that investment is not wasted and that the stockpile is managed on an optimal timescale.

There are similar issues when it comes to the fuel cycle. Is the future plan to have an open fuel cycle in which the fuel is used once in

a reactor and then stored pending final disposal or is the plan to reprocess the spent fuel so that the unused uranium and plutonium can be recycled in fresh fuel? The THORP reprocessing plant at Sellafield, scheduled for closure in 2018,⁶³ separates plutonium and uranium from the fission products and minor actinides in the spent fuel so that the plutonium and uranium can potentially be recycled in new fuels. The link with the availability and price of uranium is evident – the recourse to reprocessing and the use of MOX fuel and/or development of fast reactors become economic if uranium demand and market price increase substantially. Therefore, if careful consideration is not given to the future nuclear energy landscape, there is the possibility that UK expertise in the fuel cycle will be lost and need to be redeveloped at a later date. This underlines the importance of a roadmap that joins up near term requirements with a longer term vision.

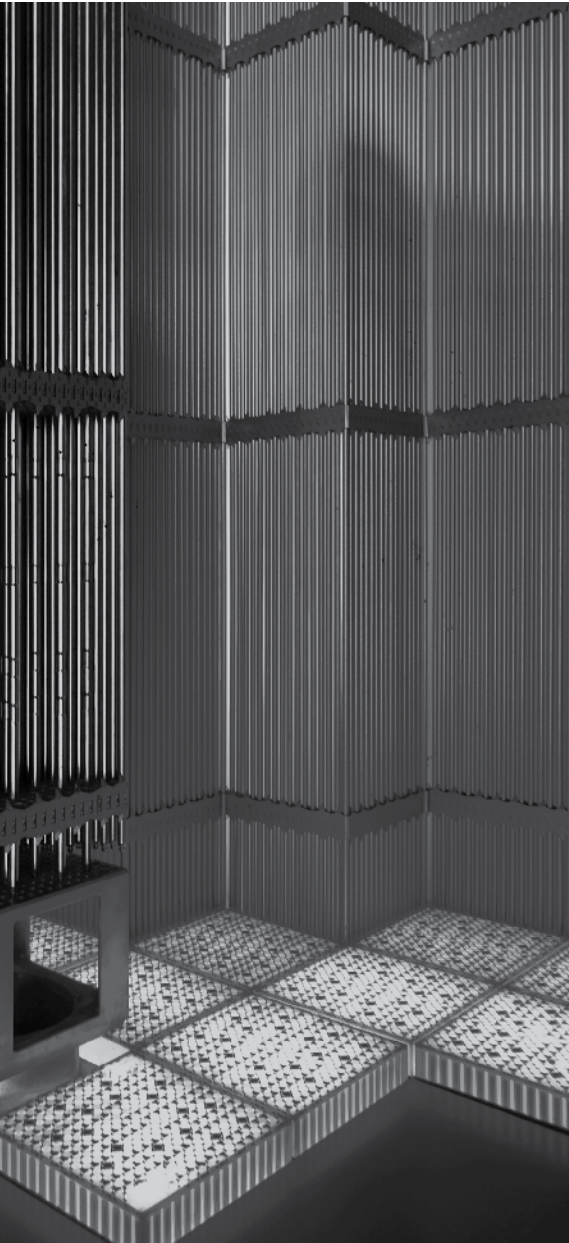
The first steps in the development of a roadmap have been embarked upon through the Energy Research Partnership (ERP) 'UK Nuclear Fission Technology Roadmap' published in February 2012.⁵ This should be further developed as a matter of priority.



⁶¹ GE-Hitachi: 'PRISM Sodium-Cooled Reactor' http://www.ge-energy.com/products_and_services/products/nuclear_energy/prism_sodium_cooled_reactor.jsp

⁶² I-Nuclear (April 3, 2012): 'UK NDA signs contract with GE Hitachi for study on Prism reactors for Pu disposition' <http://www.i-nuclear.com/2012/04/03/uk-nda-signs-contract-with-ge-hitachi-for-study-on-prism-reactors-for-pu-disposition/>

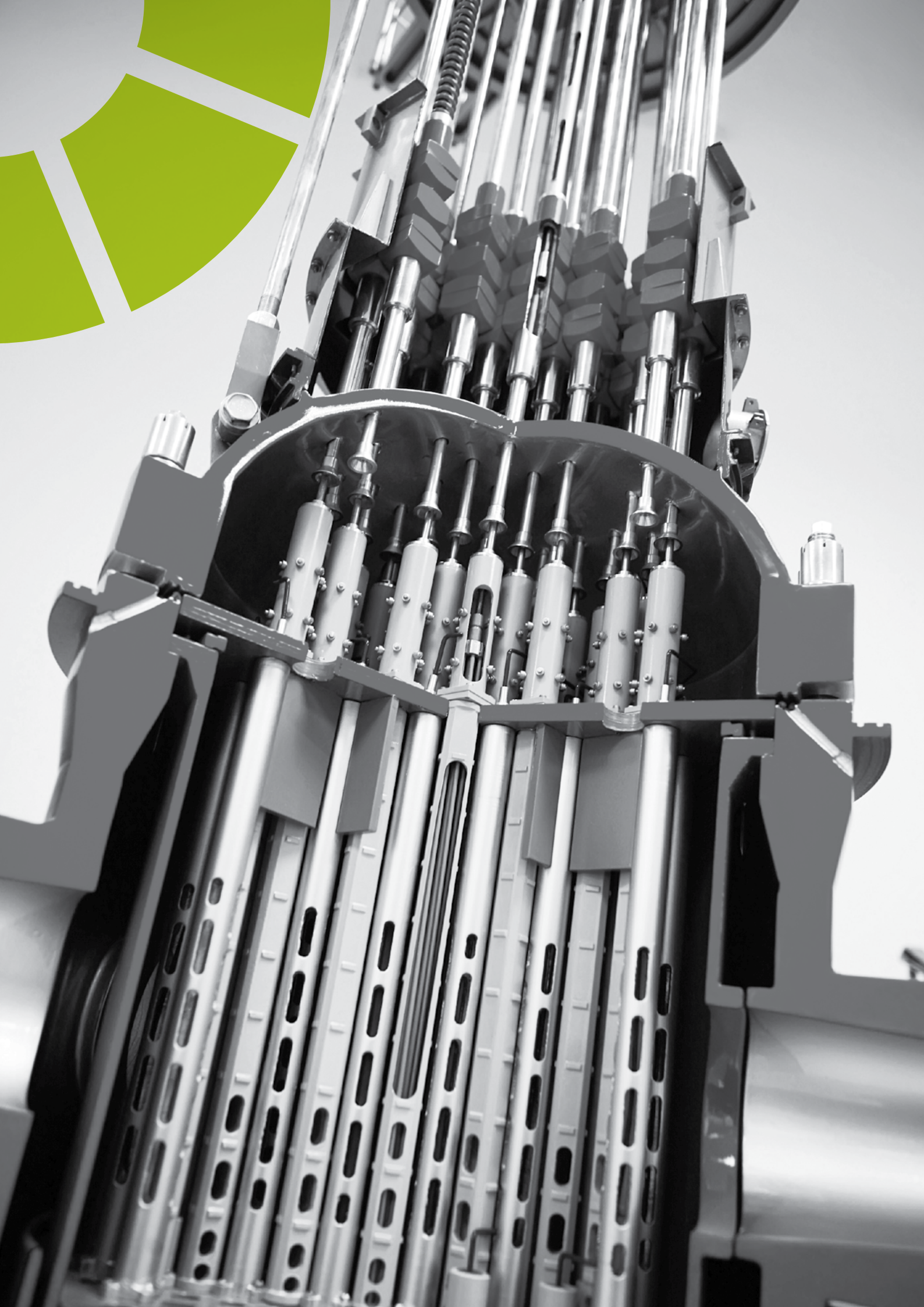
⁶³ Nuclear Decommissioning Authority (NDA) (2011): 'Oxide Fuels Credible Options' <http://www.nda.gov.uk/documents/upload/Oxide-Fuels-Credible-Options-November-2011.pdf>



Conclusions and Recommendations

- Development of a national roadmap for nuclear energy is a high priority, and must take into consideration factors such as fuel cycle options. The role of the proposed high level Nuclear Policy Council, or similar, would be to establish and monitor progress along this roadmap.
- With the pending closure of key fuel cycle facilities at Sellafield in the next few years, the UK faces difficulties regarding continuity of knowledge and loss of expertise. If fuel cycle options are to remain open for the UK in the coming years as its nuclear programme develops, it is imperative that in the interim period at least a minimum level of required skills and competences are maintained, even if only in an intelligent customer/custodian capacity.
- Explicitly excluding MOX from the Regulatory Justification and GDA as part of the preliminary licensing process could result in substantial additional licensing and plant construction work at a later date, indicating the need for more coherent planning regarding energy policy and plutonium management.





Should the UK embrace thorium?

The concerns about proliferation and nuclear waste have led some to increased focus on alternative fuel cycles, eg, that based on thorium, which potentially mitigate some of the challenges of the uranium fuel cycle.

One of the attractions of thorium is that it is three to four times more abundant than uranium (though this may not be the case for exploitable reserves). Countries such as India and Norway have considerable natural thorium resources and India in particular is actively pursuing the development of a thorium fuel cycle.

Thorium alone cannot be used as fuel, since it exists in nature only as the isotope ^{232}Th , which is not fissile. This means a more complicated fuel cycle is required, often involving a mix of reactors in order to breed fissile ^{233}U from ^{232}Th and then fully exploit the ^{233}U . For example, India's plans include three stages:⁶⁴ 1) 'CANDU-like' pressurised heavy-water reactors using natural uranium fuel and normal light-water reactors (LWR) produce plutonium, 2) fast breeder reactors (FBR) then use the plutonium to breed ^{233}U from thorium, and finally 3) advanced heavy-water reactors (thermal breeders) burn the ^{233}U while breeding more from thorium. In this case it is the ^{233}U that provides in the long term the bulk of the fissile material (as opposed to ^{235}U and ^{239}Pu in the uranium-plutonium fuel cycle). However, this three stage cycle requires several decades before being fully able to exploit thorium, and India is only now nearing completion of the first stage-2 reactors, with the first final stage reactor not foreseen before the 2020s. There are also alternative thorium fuel cycles involving only two stages. Being fissile, ^{233}U could also be used in a weapons programme (instead of ^{235}U or ^{239}Pu). Indeed, the US explored the development of a mixed ^{233}U -plutonium device in Operation Teapot.

However, a particular problem with the thorium fuel cycle is the inevitable production of small quantities of ^{232}U , which has a relatively short half-life (69 yrs) and whose decay series includes a number of high-energy gamma decays, making handling spent fuel and reprocessing challenging, though it is argued that this also means the thorium cycle is more proliferation resistant than the U-Pu cycle.

Building a thermal thorium reactor is a little more challenging than a uranium fuelled reactor as it can be difficult to breed more ^{233}U than is consumed. Correspondingly, the neutron economy of the reactor needs to be very good. On the other hand, it is possible to breed fissile material with slow neutrons (ie, thermal as opposed to fast), and it is also possible to use a thorium-plutonium fertile mix to destroy plutonium while building up fissile ^{233}U . Moreover, thorium fuel leads to significantly higher safety margins in most reactor designs⁶⁴ (eg, thorium oxide melts at a higher temperature than uranium or plutonium oxide – indeed, it has the highest melting point of all known oxides).

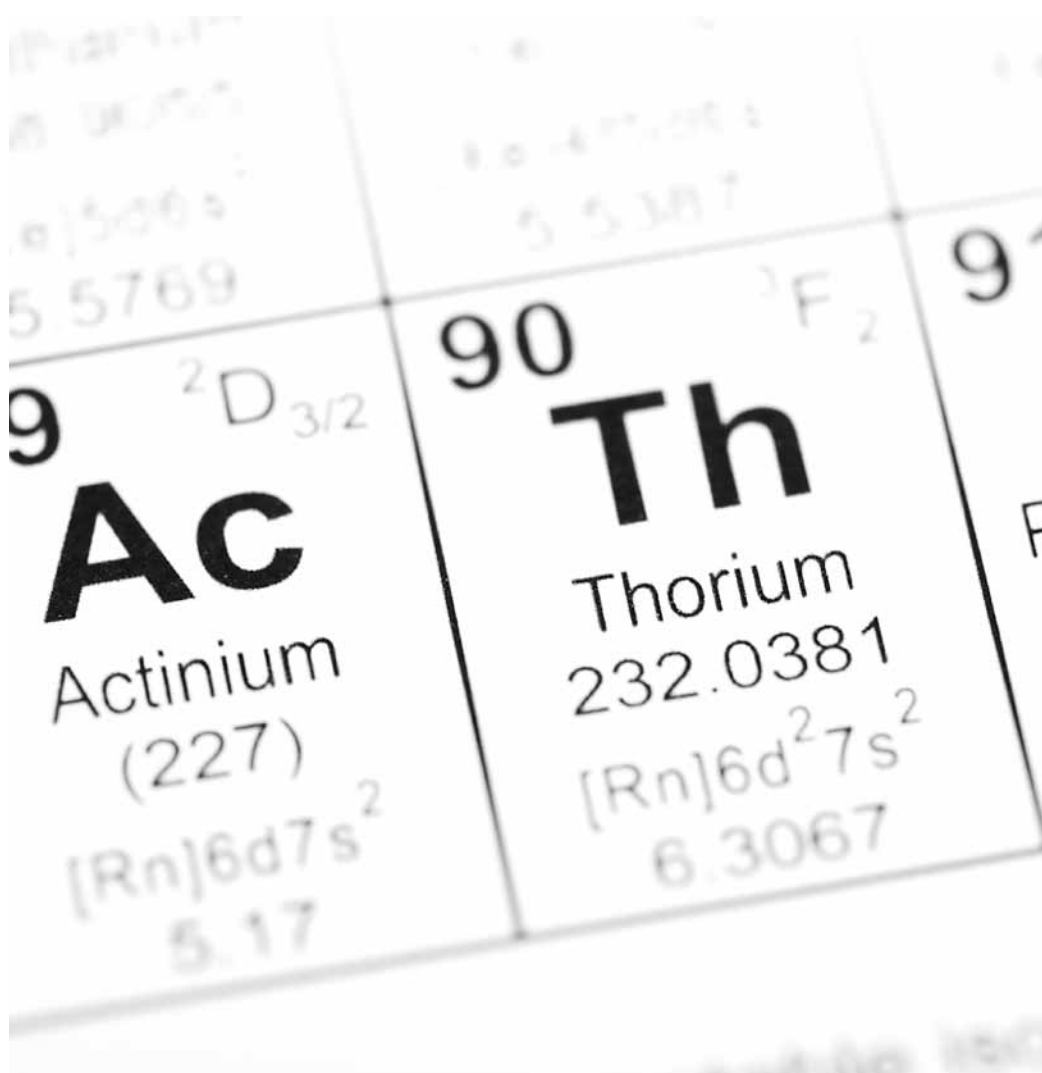
The concept was originally developed in the USA at Oak Ridge during the 1950s–70s, initially as part of the military programme and with the highlight being the operation, for four years at the end of the 1960s, of a lithium-beryllium-uranium molten salt reactor at ambient pressure and a temperature of 600–700°C. The pilot was successful but demonstrated there were a number of challenging corrosion issues to be resolved.

⁶⁴ World Nuclear Association: Thorium <http://www.world-nuclear.org/info/inf62.html>

Design work continued in the US on a U-Th molten salt breeder in the 1970s, though funding was stopped in 1976. At about this time, though not using molten salt, a 1MWth aqueous homogenous suspension reactor was operated in the Netherlands with continuous reprocessing outside the core to remove fission products, demonstrating one of the attractive features of fuel in liquid form.

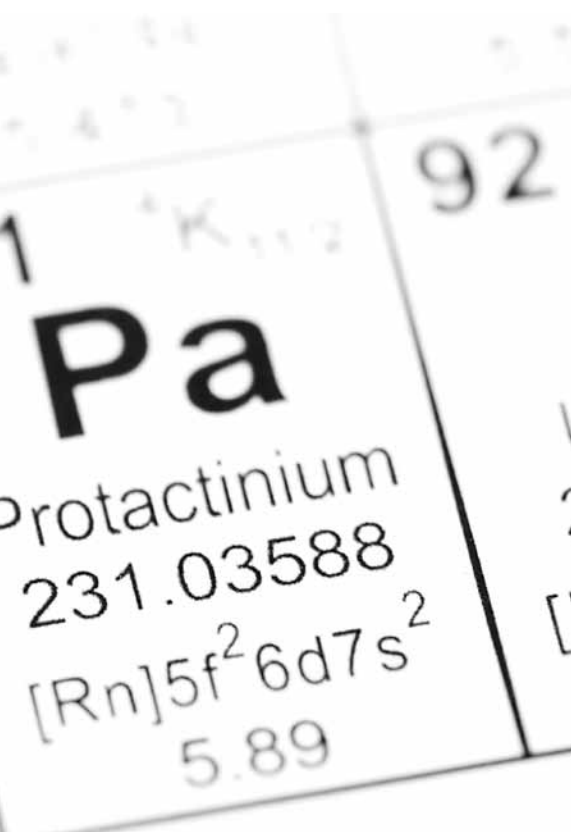
The Molten Salt Reactor is currently receiving a limited revival in interest by virtue of the fact it has been included as one of the six generic designs for investigation by GIF. It has also been argued that since the fuel is already molten, core meltdown issues are avoided. However, despite its inclusion as one of the six GIF advanced concepts, GIF members such as Russia and, more recently China,⁶⁵ seem mainly interested in funding related research on a purely national basis or with only limited cooperation at the international level.

There are advantages in the use of thorium as a fuel, not least of which is the abundance of the element. However, the (2010) National Nuclear Laboratory position paper observes that, 'It is estimated that it is likely to take 10 to 15 years of concerted R&D effort and investment before the thorium fuel cycle could be established in current reactors and much longer for any future reactor systems' and also that, 'The thorium fuel cycle does not have a role to play in the UK, other than its potential application for plutonium management in the longer term'.⁶⁶



⁶⁵ Energy From Thorium (2011): 'China Initiates Thorium MSR Project' <http://energyfromthorium.com/2011/01/30/china-initiates-tmsr/>

⁶⁶ National Nuclear Laboratory (2010): 'Position Paper: The Thorium Fuel Cycle – An Independent Assessment by the UK National Nuclear Laboratory' NNL: Warrington http://ripasets.eu.s3.amazonaws.com/www.nnl.co.uk/_files/documents/aug_11/NNL_1314092891_Thorium_Cycle_Position_Paper.pdf



Conclusions and Recommendations

- In the short term the UK should continue to pursue technologies associated with the uranium-plutonium fuel cycle. The drive of countries such as India towards development of the thorium fuel cycle may mean this option could become more attractive in the future. Given the historic national expertise in the nuclear fuel cycle, it would be sensible to pursue thorium research at a level to maintain national expertise and to keep up with international developments.



Is nuclear energy safe?

What are the public perceptions?

The arguments against nuclear energy revolve largely around safety (mainly the impact of radiation on human health and the environment), the closely related issue of waste disposal, and security concerns linked with terrorist attack and proliferation of nuclear weapons. Regarding safety, the accidents of Three Mile Island, Chernobyl and Fukushima are often used to frame public concerns. It is important that any discussion is based on accurate and transparent information and that the risks are properly understood.

The current (US) regulatory limits by which nuclear power stations are licensed correspond to a maximum of one significant core damage incident every 10,000 years.⁶⁷ A historical global analysis of the safety record of civil nuclear power from its origins in the 1950s reveals a significant core damage frequency almost ten times higher (eleven failures in 14,400 reactor years, the most significant being the accidents above). Nonetheless, US utilities aim to operate their plants so that the core damage frequency is ten times lower than the regulatory limit, and this is likely to reflect general practice world-wide. Furthermore, the theoretical safety performance of the latest designs is probably at least ten times better still, equivalent to less than one core incident per million years in the case of the EPR and AP1000, achieved by completely redesigning the safety systems to employ passive features, ie, that work by natural processes as much as possible, thereby enabling safety functions to be maintained without AC or battery power.

In a scenario of an operating fleet of ten to twenty EPRs or AP1000s, such as is foreseen in the UK, this would mean a 1 in 50,000 year possibility of a significant incident.

Regarding terrorist attack (or worst case accident scenario), modern reactors are designed to withstand the impact from a fully laden Boeing 747; the former US NRC (Nuclear Regulatory Commission) Chairman Dale Klein has said, 'Nuclear power plants are inherently robust structures that our studies show provide adequate protection in a hypothetical attack by an airplane'.⁶⁸ The UK GDA process requires the reactors to be constructed to the same specifications.⁶⁹

If a severe accident did happen, involving release of radiation into the environment, how serious would the radiological impacts be? This is impossible to predict without detailed knowledge of the so-called source term (inventory of various radionuclides released into the environment), the weather

⁶⁷ W. Ferguson, C. D (2011): 'Nuclear Energy: What Everyone Needs to Know' Oxford University Press

⁶⁸ United States Nuclear Regulatory Commission (2007): 'Statement from Chairman Dale Klein on Commission's Affirmation of the Final DBT Rule' <http://www.nrc.gov/reading-rm/doc-collections/news/2007/07-013.html>

⁶⁹ Health and Safety Executive (2006): 'Safety Assessment Principles for Nuclear Facilities, 2006 Edition, Revision 1' <http://www.hse.gov.uk/nuclear/saps/saps2006.pdf>



and wind patterns, the type of terrain, the population distribution and local farming and other activities, and the countermeasures taken by the emergency authorities. A fundamental limitation remains our lack of knowledge of the link between cancer incidence, and indeed other health problems, and exposure to low doses of radiation. This is essentially because the incidence of cancer in the population from all causes is very high – in 2010, 157,250 people died from cancer in the UK⁷⁰ – and epidemiologically it is very difficult to identify those that may have resulted from exposure to radiation, from whatever source. Better understanding of the 'dose-risk' relationship at low doses is essential in order to quantify the true risk, and it is increasingly accepted that individual genetic make-up determines people's sensitivity to radiation. Research programmes such as those funded via the Euratom Framework Programme and under the umbrella of the Multidisciplinary European Low Dose Initiative (MELODI)⁷¹ are addressing this challenging issue. In the absence of more precise information, the dose-risk relation at low dose is assumed to be a linear extrapolation of the (much better known) relationship at higher doses, essentially assuming that the risk is proportional to dose even at low levels – therefore the 'linear no-threshold' (LNT) hypothesis forms the basis of all regulatory controls to limit radiological risk. This is despite the absence of any epidemiological evidence indicating a risk from exposure to normal natural background levels of radiation, though it is believed that long term exposure to radon (a naturally occurring radioactive gas) is responsible for a small fraction of lung cancers, and could be particularly important in areas of Cornwall.⁷²

Within Europe, there have been calls for a long term study of the health effects of the 1986 Chernobyl accident (ARCH initiative⁷³). The latest UNSCEAR (UN Scientific Committee on the Effects of Atomic Radiation) 2011⁷⁴ report on the health effects of the world's worst nuclear accident indicates that there were 28 deaths shortly after the accident amongst the emergency workers and 15 cases of thyroid cancer deaths in children (which could have been avoided if tablets containing inert iodine had been distributed to the local population as in Japan and as foreseen around all European reactors as part of the emergency countermeasures). The World Health Organisation (WHO) report on Chernobyl health effects,⁷⁵ which is endorsed by the IAEA and UNSCEAR, indicates in addition that amongst the most exposed groups in Belarus, Ukraine and Russia one might expect up to 4000 additional cancer deaths (integrated over a number of decades) as a result of the additional radiation exposure, and a similar number in the wider population from a strict application of the LNT hypothesis, even though these figures are unlikely to be substantiated epidemiologically. That said, the exceptional nature of the Chernobyl accident is widely accepted – lack of regulatory oversight and safety culture, unforgiving design not licensable outside the old USSR, and inadequate emergency preparation and response – as are the widespread detrimental impacts on mental health (depression, alcoholism, suicide) from numerous causes: displacement of populations, associated stress and fear of radiation, stigmatisation of affected populations, compounded by the dissolution of the USSR and resulting disruption of services such as

healthcare shortly after the accident. Even though the circumstances at Fukushima are very different, and health effects from radiation are expected to be extremely limited, there will undoubtedly be effects on the mental wellbeing on many of those involved. In any event, the indirect health impacts following such incidents are widely believed to far outweigh the consequences of the resulting low levels of exposure.⁷⁶

Though there is no room for complacency about radiation safety, one could rightly enquire whether these psychological consequences result from our inability to appreciate the true risks, resulting in the application of an overly conservative precautionary principle. Is there a better balance to be found between limiting public exposure and stigmatising industrial practices that involve radiation? In all countries, radiation protection standards are set by government authorities, generally in line with recommendations by the International Commission on Radiological Protection (ICRP), and coupled with the requirement to keep exposure as low as reasonably achievable (ALARA), taking into account social and economic factors. Current standards limit the permissible additional radiation dose to members of the public from artificial sources to 1 mSv/year, and have led to intervention levels, requiring evacuation, of 20 mSv/year being applied in areas around Fukushima. This should be compared with average radiation levels in the UK of ~2.7 mSv/year (mostly from natural background, though about 0.5 mSv/year is from medical applications), with people living in Cornwall receiving on average three to four times higher doses from the natural background.

⁷⁰ Cancer Research UK (2012): 'All cancers combined statistics – Key Facts' <http://info.cancerresearchuk.org/cancerstats/keyfacts/Allcancerscombined/>

⁷¹ Multidisciplinary European Low Dose Initiative (MELODI) <http://www.melodi-online.eu>

⁷² Health Protection Agency (10 January 2012): 'Cornish radon hotspot targeted' http://www.hpa.org.uk/webw/HPAweb&HPAwebStandard/HPAweb_C/1317132257592?p=1317132140479

⁷³ International Agency for Research on Cancer – Agenda for Research on Chernobyl Health (ARCH) initiative <http://arch.iarc.fr/> and a critical review: http://www.melodi-online.eu/NoteARCH_SRA.pdf

⁷⁴ UN Information Service (28 February 2011): 'New Report on Health Effects due to Radiation from the Chernobyl Accident' <http://www.unis.unvienna.org/unis/en/pressrels/2011/unisinf398.html>

⁷⁵ World Health Organization (2006): 'Health effects of the Chernobyl accident: an overview – Fact sheet N° 303' <http://www.who.int/mediacentre/factsheets/fs303/en/index.html>

⁷⁶ International Atomic Energy Agency, World Health Organization and United Nations Development Programme (2005) 'Press Release. Chernobyl: The True Scale of the Accident 20 Years Later a UN Report Provides Definitive Answers and Ways to Repair Lives' <http://www.iaea.org/newscenter/focus/chernobyl/pdfs/pr.pdf>

⁷⁷ Walker, P (2011): 'Road deaths fall to record low' *The Guardian*, 30 June 2011 <http://www.guardian.co.uk/world/2011/jun/30/road-deaths-fall-record-low>

⁷⁸ <http://www.ieahydro.org/reports/ST3-020613b.pdf>

Perception of risk and actual risk are of course very different, but only by an objective comparison can we hope to understand the true nature of risks that are ever present in our lives. For example, the annual number of deaths on the roads in the UK fell just below 2000 for the first time in 2011,⁷⁷ though the UK, along with Sweden, has the lowest road death rate in the EU at about half the EU average – total deaths across the EU amount to more than 30,000 annually. This is a level of risk which most people accept. It is estimated that the number of fatalities associated with nuclear energy is, on a ‘full life cycle’ basis, amongst the lowest of any type of energy production – it is over a thousand times safer than coal⁷⁸ and even slightly lower than wind energy. **From the 50 years of experience of operating nuclear power stations, the level of fatalities is much less than generally perceived by the public, and is certainly very low in the countries of Western Europe.**

In general there is poor public awareness of the effects of radiation, including the various types of radiation and the related risks from exposure, with large variations in opinion on nuclear issues according to gender, age and socio-economic group. In addition, there has historically been significant suspicion of the nuclear industry, largely owing to the past links with the military and the associated secrecy. The more recent move towards openness and public outreach by Industry and public bodies alike is a step in the right direction, and the work of the Nuclear Decommissioning Authority (NDA) in this regard is particularly noteworthy. Increased public awareness of the true level of risk and potential impact could lead to a more informed judgement on nuclear energy and other uses of radiation, while still respecting the ALARA principle.

Conclusions and Recommendations

- **The public has a limited understanding of risks associated with radiation in general and nuclear energy in particular, often leading to heightened concerns, worry and psychological stress of those affected. It is important to address these issues in a dispassionate and rational way that places nuclear safety and the historical impacts of nuclear accidents in context. It is time for a more informed debate, in which both the academic community and nuclear industry have a role to play, and involving broad and open engagement with the media and public.**
- **Public confidence in nuclear energy is a prerequisite for large scale investment, and must be built on trust in and openness of the nuclear actors, both Industry and public bodies, in particular regarding the relationship with local stakeholders around nuclear sites.**
- **Potential benefits of nuclear energy vary widely, ranging from energy security and carbon emissions reductions, to competitiveness and local employment issues, and these should be presented as a portfolio rather than framing everything as a single issue such as ‘nuclear energy is the solution to climate change’.**



Nuclear waste:

Is there a viable management solution?

The UK has generated a substantial amount of nuclear waste from its earlier nuclear programmes, both civil and military.

The volumes of intermediate and high level waste to be disposed of from these activities are estimated to be 287,000 m³ and 1,020m³ respectively.⁷⁹ By comparison, the volumes associated with the operation of the planned new reactors will be very small. These plants will produce less irradiated fuel per unit of electricity generated, and unlike the UK's historic Magnox reactors and AGRs are not associated with large volumes of graphite waste. **As an example, a new build fleet of reactors of the same electrical installed capacity as the historic UK fleet will produce only an additional 10% of high level and intermediate level waste, yet because of their longer operating lifetimes and increased efficiency, will generate more than 140% more electricity.**⁸⁰

The disposal of all high/intermediate level and long-lived waste in a safe and environmentally responsible manner presents both a scientific and engineering challenge. The internationally accepted solution, certainly in the expert community, and the one endorsed in the CoRWM (Committee on Radioactive Waste Management) 2006 report to Government and reflected in the Managing Radioactive

Waste Safely White Paper 2008,⁸¹ is that the most radioactive and long-lived wastes, such as irradiated nuclear fuels or the residues from the reprocessing of this spent fuel, should be sealed in a deep repository in an environment that will remain geologically stable over the period during which the waste continues to present a radiation hazard, which could be tens of thousands of years. This 'confine and contain' strategy, which ensures that the radiation decays to safe levels before there is any degradation in the containment barriers, is the principle behind management of all radioactive waste, whether it concerns the short-lived wastes that are currently disposed of in engineered surface or near-surface repositories in many countries, or the much more radioactive and longer lived nuclear wastes destined for geological disposal. In the latter case the disposal should be at a depth sufficient to avoid accidental man-made interference and possible disruption by future glacial activity, which is considered to be at least 400–500m. The repository would stay open for around 100 years, but eventually would be sealed leaving the waste in a passively safe condition without the need for further active measures by future society.

⁷⁹ Report prepared for the Department of Energy & Climate Change (DECC) and the Nuclear Decommissioning Authority (NDA) by Pöyry Energy Limited (2011): 'The 2010 UK Radioactive Waste Inventory: Main Report' Nuclear Decommissioning Authority: Cumbria <http://www.nda.gov.uk/ukinventory/documents/Reports/upload/2010-UK-Radioactive-Waste-Inventory-Main-Report.pdf>

⁸⁰ National Nuclear Laboratory (2011): 'Position Paper: UK Nuclear Horizons – An Independent Assessment by the UK National Nuclear Laboratory' NNL: Warrington http://ripassets.eu.s3.amazonaws.com/www.nnl.co.uk/_files/documents/sep_11/NNL_1315903177_Position_Paper_from_NNL_-_UK_N.pdf

⁸¹ Defra, BERR and the devolved administrations for Wales and Northern Ireland (2008): 'White Paper: Managing Radioactive Waste Safely. A Framework for Implementing Geological Disposal' TSO (The Stationery Office): Norwich <http://mrws.decc.gov.uk/assets/decc/mrws/white-paper-final.pdf>

In this way, no burden is passed on to future generations who have not benefitted from the electricity produced by the nuclear power programme, though it is likely that some form of long-term stewardship will be undertaken for many years post-closure.

Though management and disposal of short-lived waste is now a mature industrial practice in most countries with nuclear energy programmes (eg, UK's Drigg facility in Cumbria), there are currently no operating geological repositories for high level radioactive waste anywhere in the world. Most nuclear programme countries have active R&D programmes, and the most advanced carry out research in underground research laboratories (URLs) constructed in promising host rock formations in order to investigate the geological environment, the performance of engineered barriers and the associated technology. In Europe, URLs either are operating or have operated in the past in Belgium, Germany, Finland, France, Sweden and Switzerland, covering a range of host rocks from granite to salt and various clays, and providing a focal point for much of the national as well as EU collaborative (eg, through the Euratom programme) research over the last 20 years.

Within the UK, the NDA is responsible for developing the detailed disposal concept and overall strategy, piloting the licensing process and constructing the repository. According to NDA plans for both the timeframe and construction of a future Geological Disposal Facility (GDF),⁸² it is anticipated that the facility will be constructed by 2040 and will begin accepting intermediate-level waste at this point. It would then be licensed to accept legacy high level waste and spent fuel from existing power stations around 2075. Later, in 2130, spent fuel from the new

build power stations would be transferred to the GDF, which would be closed in 2175. The NDA's predecessor, UK NIREX Ltd., was an important partner in the European cooperative research effort in the past, and the NDA is maintaining this important interaction with key European research actors, in particular through its membership of the Implementing Geological Disposal of Radioactive Waste Technology Platform (IGD-TP).⁸³ Being less advanced in this endeavour than a number of other European countries, the UK stands to benefit significantly from such alliances at the R&D level.

Indeed, the development of disposal sites elsewhere, for example in Sweden and Finland, means that lessons can be learned and applied in the UK context, not only regarding scientific and technical issues but also on interaction with civil society and overall management of the process of repository siting and development. In the 1980s, early attempts by NIREX to site low level nuclear waste repositories at Billingham, Elstow, Bradwell, Fulbeck, and South Killingholme, were subsequently abandoned owing to local opposition resulting largely from lack of local engagement and communication. This was a classic case of 'decide-announce-defend' (DAD), which was increasingly proving ineffective in the siting of controversial facilities across the world, especially in cases where the NIMBY – 'not in my backyard' – syndrome was so potent. In the 1990s, NIREX was to suffer another setback, this time in its high-level waste / GDF programme when a public enquiry rejected its appeal against a local authority decision to refuse planning permission to construct a URL (so-called 'rock characterisation facility' – RCF) in the region of Sellafield. The reasons cited were the scientific uncertainties and technical deficiencies in NIREX's proposal.

In recent years, the only truly successful processes have been those that have sought to engage and enter into a meaningful dialogue with local communities in the vicinity of potential sites, whether it concerns low level surface facilities or GDFs. This interaction must be on the basis of trust and transparency, and can take many years, if not decades, to be effective. At the start of the process, voluntarism on the part of the local communities willing to be considered as a potential host can be effective, though must be linked with specific guarantees and veto rights (at least up to a certain point in the process). This has been effective in countries like Sweden and Finland, but the overall time for this process can be very long – in Sweden it will have been 40 years from the start of the programme (when it too suffered setbacks as a result of DAD approaches) to final completion of the GDF, expected in the next ten years. The attractions to local communities include employment, but also long-term socio-economic investments in addition to expenditure associated with the repository construction and operation. In the case of the final selection in 2009 of the site for the Swedish GDF, there was fierce competition between two bidding communities, both demonstrating public support of 80–85% for hosting the facility. The eventual winner, Forsmark to the North of Stockholm, was actually the site with the slightly lower local support, but the decision was taken on the basis of host rock quality. Following this and other examples in Europe and around the world, the NDA has also instigated a process of site selection through local voluntarism, though so far this has resulted in only one potential site close to Sellafield, corresponding to the communities represented by Allerdale Borough Council, Copeland Borough Council and Cumbria County Council. There are signs that other communities are also considering this option (eg, Shepway District Council in Kent⁸⁴).

⁸² Nuclear Decommissioning Authority (March 2010): 'Geological Disposal: Steps Towards Implementation' Nuclear Decommissioning Authority: Didcot <http://www.nda.gov.uk/documents/upload/Geological-Disposal-Steps-Towards-Implementation-March-2010.pdf>

⁸³ Implementing Geological Disposal of Radioactive Waste Technology Platform (IGD-TP) www.igdtp.eu

⁸⁴ BBC News (16 May 2012): 'Kent nuclear waste bunker proposal considered' <http://www.bbc.co.uk/news/uk-england-kent-18086988>

⁸⁵ Nirex (1997) 'Science Report: Sellafield Geological and Hydrogeological Investigations – The Geological Structure of the Sellafield Site' Report no : S/97/007 United Kingdom Nirex Limited: Didcot <http://www.nda.gov.uk/documents/upload/Sellafield-geological-and-hydrogeological-investigations-the-geological-structure-of-the-Sellafield-site-1997.pdf>

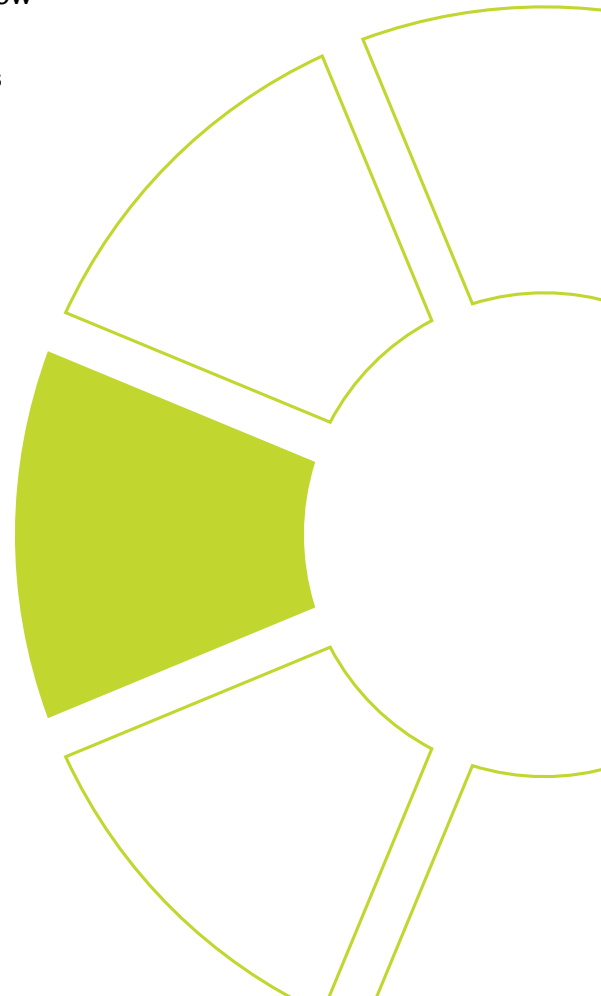
In the case of the repositories in Scandinavia the host rock is granite. France is on course for the commissioning of its GDF in clay host rock around 2025, shortly after those in Sweden and Finland. Other national programmes are also investigating clay as a potential host rock, and Germany has extensively developed the salt disposal concept. The proposed repository host rock at Sellafield is within the Borrowdale Volcanic Group (BVG), a succession of mainly volcanic rocks,⁸⁵ and the disposal concept would therefore be similar to the Scandinavian examples. However, the site is situated between three fault zones, underlining the difficulties in marrying ideal geological conditions with a willing host community. The local population around Sellafield have lived with the nuclear industry for over half a century, and as well as relying on the nuclear industry for employment, they have become more familiar and trusting of the sector as a whole. Moreover, much of the waste is already stored at Sellafield and hence the arguments for disposal locally are more compelling (though it is interesting to note that in the case of the 2009 decision in Sweden, the competing site at Oskarshamn to the South of Stockholm was actually the location of the Swedish centralised interim spent fuel storage facility, so in this case proximity of the waste to the final site was not a deciding factor). Nonetheless, regarding construction and long term demonstration of safety, the local geology around Sellafield may present more difficulties than other potential sites in the UK. Furthermore, putting all one's eggs in the same basket would create a problem later if the Cumbrian community were to withdraw.

Conclusions and Recommendations

- **Engagement in and commitment to a process of GDF siting and construction is crucial in order to give confidence to all stakeholders and the public regarding new build and the safe and responsible management of the whole nuclear fuel cycle. In this process, voluntarism and a partnership approach with potential host communities has an important part to play, and the NDA and the Government must explore all avenues and options, while at the same time ensuring that the geological conditions of the final selected site are adequate to guarantee long-term confinement.**
- **Cooperation with European partners regarding both technical R&D as well as waste governance issues, involving exchange of know-how and best practice, is essential, and the early completion and operation of GDFs in countries like Sweden, Finland and France will provide a considerable confidence boost to all other national high level waste disposal programmes in the world, including in the UK.**
- **The current UK strategy of seeking volunteering communities to host a geological repository has been found to be successful elsewhere. However, there is a fundamental weakness if only one community steps forward, since this limits options and potentially increases costs if additional engineering is needed because of more challenging geological conditions. The Government together with the NDA need to reconsider whether enough information is being provided to potential host communities and whether the incentives for them to engage in the site selection process are sufficiently attractive.**

Concluding comment

The UK is now at a crossroads in terms of electrical energy supply – how should the energy generation landscape be reshaped? The key drivers are the need to reduce greenhouse gas emissions, in order to minimise potential climate change, and to maximise national energy security. This will involve less coal, perhaps less gas, more renewable energy and greater energy efficiency. Nuclear energy should be a significant part of the solution as it has the potential to provide low cost, low carbon electricity. Rebuilding the UK as a suitably qualified nuclear nation, capable of building new stations and developing new technologies, is a priority. There are, however, a number of hurdles which stand between now and the eventual construction of new power stations. Getting the solution right now is essential as it will have significant consequences for generations to come.





Section III

The issues in depth



Nuclear energy in context

In 2010, 441 nuclear reactors in 31 countries generated 12% of the world's electricity.⁸⁶ The 104 reactors in the USA provided almost 20% of its electricity, while the 58 reactors in France provided close to 75%. A few months before the Fukushima disaster, Japan had 54 operating reactors.

Fifteen countries were building 68 reactors between them: 28 of these were in China (which had 13 operating reactors) and 12 in Russia (which had 32). Three-fifths of the operating reactors, and five-sixths of those under construction, were Pressurised Water Reactors (PWR).

Civil nuclear power technology has developed over a number of decades and has been characterised, until now, by three stages of development. The initial prototypes were constructed in the 1950s and 60s and culminated in the construction of the first series of civil nuclear power reactors coupled to the grid, which included the Magnox plants in the UK (gas-cooled graphite-moderated reactors capable of operating with natural uranium in metallic form clad in a magnesium alloy fuel can – Magnox being short for **m**agnesium **n**on-**o**xidising). The construction of the second generation of reactors started at the beginning of the 1970s and marked the widespread appearance of Light Water Reactors (LWR): either Pressurised Water Reactors (PWR) or Boiling Water Reactors (BWR), both using normal water as coolant and moderator. The original designs originated in the USA and, independently, in Russia in the 50s, the PWR in particular having been developed as an effective power plant for use in nuclear submarines. All LWR designs required the uranium fuel to be slightly enriched in the fissile isotope (²³⁵U) and, therefore, relied on parallel advances in mass uranium enrichment technology. Though more refined designs of these reactors have evolved since the 70s, in particular as a result of operational feedback, the vast majority of reactors currently in operation worldwide are essentially of the same 'Gen-II' stock.

The production of energy by fission is in principle very simple, which is in part what makes the technological approach so robust. In nuclear fission reactors a chain reaction occurs. The nuclei of the isotope of uranium ²³⁵U absorb a neutron causing them to fission (split) into two fragments. In the fission process further neutrons are released which in turn are themselves captured, creating fission. In order that the process does not runaway, the number of neutrons is controlled using 'control rods' which capture neutrons and may be inserted or removed from the reactor to decrease or increase the number of neutrons inside.

In order to maximise the probability of the ²³⁵U capturing, or absorbing, a neutron the neutrons have to be slowed down or moderated. Neutrons from fission are produced at high energies (fast neutrons), whereas it is at low energies that the probability for capture is highest. The neutrons at these lower energies are known as thermal neutrons as their velocities are characteristic of that being induced by their thermal environment. Typical moderators are light nuclei such as hydrogen or carbon. Correspondingly either water or graphite is used in reactors – or heavy-water which contains deuterium rather than hydrogen in the water molecules.

The fission process generates energy through the kinetic energy (motion) of the fission fragments. These fission fragments travel less than a millimetre and hence are trapped inside the uranium fuel. As they slow down, the fission fragments impart their energy as heat to the fuel. In a PWR, the water, which is pressurised to keep it water (to stop it boiling), is heated by the fuel rods and then through circulation cools them and takes the heat away from the reactor

core. A heat exchanger is then used to convert water in a secondary circuit (which does not enter the reactor) into steam, which generates electricity in a turbine (as with a coal or gas-fired power station).

As noted above, there are many designs of reactor, for example the Boiling Water Reactor (BWR), which does not have two separate water circuits, as in the PWR, but the water is allowed to turn into steam inside the core. The UK has no BWRs (the type of reactor at Fukushima) and one operating PWR – Sizewell B, commissioned in 1995.

Important evolutionary developments have been integrated into the latest LWRs (PWRs) available today (eg, the AP1000 and EPR), especially with regard to design lifetime (typically 60 years compared with 40 years in the past) and behaviour under severe accident scenarios. These new designs are classified as Gen-III or III+, and the first commercially available reactors of this generation are now under construction. Most, if not all, reactor vendors worldwide have an approved Gen-III model to propose to potential customers and any nuclear new build over the next two or three decades will largely involve these designs.

Most of the UK's current reactors are actually cooled by carbon dioxide gas and use graphite as a moderator. When the UK began developing civil nuclear power, in the 1950s, it developed its own technology to use natural uranium, because it did not have access to the enriched uranium (with a higher proportion of the ²³⁵U isotope) needed in water-cooled reactors. Magnox reactors use graphite moderators rather than water moderators.

The UK built 26 reactors at 11 stations, commissioning one of the world's first civil nuclear power stations at Calder Hall in 1956. The early reactors at Calder Hall and Chapelcross were also used to produce plutonium for the weapons programme in addition to producing electricity.

The government initially expected these stations to be cheaper than coal-fired electricity, treating the plutonium that they produced as a valuable by-product and failing to predict the rapidly falling costs of coal-fired power as those plants became larger and more efficient. The plutonium was soon seen as a waste that had to be disposed of, and Parliament was subsequently told that the cost of the programme was 'pretty considerable'.⁸⁷

The UK announced its second programme of nuclear power stations in 1964, the year after General Electric had announced a cost breakthrough with a Boiling Water Reactor planned for Oyster Creek in New York State. The Government had to referee an argument between the UK's Atomic Energy Authority, which wanted to promote its own Advanced Gas-cooled Reactor (AGR) design – which, like Magnox, used graphite moderators – and the Central Electricity Generating Board, which wanted to use one of the water-moderated designs that were starting to emerge as the international standard. The compromise was to invite the UK's industrial consortia to tender to build reactors of either type and, perhaps surprisingly, an AGR design emerged as

the winner. The programme was beset by constructional and financial problems, as the full-size stations proved far harder to build than the first prototype. Three of the five stations which started construction in the 1960s were not completed until the mid to late 1980s. A significant issue was the fact that there was not a single reactor design as used to build up the nuclear fleet in France, but there were many different ones as the reactors evolved from the first ones built at Calder Hall and Chapelcross.

By 1980, the Government was ready to allow the electricity industry to build a series of PWR stations, and work started at Sizewell B in 1988. However, that was the year in which the decision to privatise electricity was announced. Privatisation, coupled with the election of an anti-nuclear Labour Party to government in 1997, put a two-decade stop to further nuclear investments. The (relative) transparency of private sector accounting revealed that the industry had made insufficient provision for the cost of decommissioning old stations and dealing with nuclear waste, and the nuclear stations had to be withdrawn from the privatisation in 1989. Neither the Government nor the privatised companies wanted to invest in nuclear power during the 1990s, although the AGR stations and Sizewell B were privatised in 1996 in a company named British Energy. Low energy prices at the start of the twenty-first century created financial trouble for British Energy, and the company was rescued by the Government in 2004. In 2008, it was bought by Electricité de France

(EDF). The following year EDF formed the new build company NNB Genco in which Centrica (owner of the British Gas brand) hold a 20% stake.

The UK is moving towards a new generation of nuclear energy. The Government would like to see the construction of ten or more reactors of the PWR type: AP1000 and/or EPR. There are a number of significant hurdles that must be overcome to get to this point as reviewed in the subsequent sections. Moreover, there exist challenges in determining the future UK fuel cycle, open or closed, future reactor technologies on the timescale of 40+ years, geological disposal of the nuclear waste and understanding public opinion. Here the issues are reviewed and specific recommendations made and/or conclusions drawn.

In the sections that follow, this report examines eight areas shown by the Commission's deliberations to be of key importance in thinking about the future of nuclear energy in the UK: energy policy, challenges in nuclear new build, the nuclear fuel cycle, future nuclear technologies, research and development, geological disposal, public opinion, and training and educational programmes. In each case the report offers specific conclusions and recommendations.

⁸⁶ International Atomic Energy Agency (2011): 'Nuclear Power Reactors in the World, Reference Data Series No. 2' IAEA: Vienna http://www-pub.iaea.org/MTCD/Publications/PDF/RDS2_web.pdf and BP: (June 2011) 'BP Statistical Review of World Energy' BP: London http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/pdf/statistical_review_of_world_energy_full_report_2011.pdf

⁸⁷ Sir Christopher Hinton, Chairman of the Central Electricity Generating Board, giving evidence for Select Committee on Nationalised Industries (1963). Reference – House of Commons, Select Committee on Nationalised Industries (1963): 'Report from the Select Committee on Nationalised Industries: The Electricity Supply Industry' HC 236 of 1962/3, HMSO: London

Energy policy

2.1 Background

Energy policy-makers face what is sometimes described as a trilemma – they may have to choose between policies that will raise the cost of energy, reduce its security of supply, or worsen its impact on the environment. At times, a new technology will appear that is thought to offer benefits for more than one of these objectives. In the 1950s, nuclear energy was portrayed as a low-cost option and the UK's programme was expanded shortly after the Suez crisis highlighted the country's dependence on imported fossil fuels. In the 1990s, new gas-fired stations allowed the UK to diversify its fuel supplies away from coal and to reduce its emissions of sulphur dioxide, a major cause of acid rain, while helping to make the electricity market more competitive, driving down prices. Switching from coal to gas had the added benefit – somewhat less appreciated at the time – of reducing emissions of carbon dioxide.

2.2 Environmental Impact

Climate change is now the dominant environmental concern in UK energy policy-making. Burning fossil fuels releases carbon dioxide into the atmosphere, where much of it stays, as can be seen from the rising concentrations during 50 years of direct measurements. Carbon dioxide is one of a number of greenhouse gases that trap heat in the atmosphere, and as the rising concentration means that less of the earth's heat is radiated out into space, the planet will become warmer. This may trigger other effects on the climate, and while some of these may reduce the rate of warming, others (such as the release of methane, which is also a powerful greenhouse gas, currently trapped in the permafrost around the Arctic) would worsen it. Global average temperatures have risen significantly over most of the last 50 years, and this cannot be explained by climate models that ignore the role of carbon dioxide.

Under the Climate Change Act 2008, the UK has a legally binding target of reducing its greenhouse gas emissions by 80% of 1990 levels by 2050, and the Committee on Climate Change was set up to advise on a series of carbon budgets that put the country on course to meet that goal. While the Committee's role is to advise the government on emissions targets, it has also outlined a strategy that would allow us to meet the targets it recommends. This involves reducing the carbon emissions of the electricity sector to very low levels over the next two decades, and then using low-carbon electricity to meet an increasing proportion of our energy needs for heat and for transport. The three main kinds of low-carbon electricity that should become available to the UK are renewable power (from wind, biomass, hydro and solar energy), carbon capture and storage/sequestration (CCS) fitted to fossil- or biomass-fuelled power stations, and nuclear power.

No energy source is entirely free from carbon emissions across the full life cycle. In the case of nuclear energy there are some emissions incurred in building the station, and in uranium mining and fuel processing. Emissions from nuclear energy are generally accepted to be low.⁸⁸ Government figures indicate that it is the lowest, on a par with wind.⁸⁹

The main environmental concern associated with nuclear power is its radioactive waste. During the lifetime of the exposure of the uranium to neutrons inside the core, the ^{238}U , which is the bulk of the fuel, can capture neutrons to make heavier elements known as actinides. Some of these new elements have very long half-lives, which present significant issues in terms of storage and disposal of the spent fuel in the very long term. Initially of higher activity, but with generally shorter half-lives than actinides, the fission products formed in the fission process make up a significant fraction of the radioactive inventory of spent fuel. In addition, at the end of the

station's life, the reactor structural materials will be radioactive and must be carefully dismantled – usually after a long delay for the level of radioactivity to fall. The remaining waste must then be disposed of safely. The high level waste, comprising the fuel (or, if reprocessing is being undertaken, the fission products and the actinides in higher activity waste), is then to be disposed of in a deep geological repository.

The problem of radioactive waste is unique to nuclear power.⁹⁰ However, some other types of power station have other environmental side-effects. Coal and oil contain sulphur, which forms sulphur dioxide when the fuel is burned, leading to the creation of acid rain. The EU's Large Combustion Plant Directive now requires power stations to fit flue gas desulphurisation equipment, trapping the bulk of the emissions, or to close by the end of 2015. Similarly, burning fossil fuels in air creates nitrogen oxides, and the Industrial Emissions Directive requires stations to fit appropriate control equipment by 2020 (or close by 2023). Coal contains small amounts of pollutants such as mercury, and mining has a long history of industrial accidents.

2.3 Energy Security

Energy security can be defined as having sufficient supplies of energy (or energy services) available, when they are required, at a reasonable price. Physical interruptions to the supply of oil have been rare, in part because it can be transported relatively easily, but this also means that concerns over the supply of oil from any part of the world translate into price rises, even for countries that do not directly import from that region. Gas is harder to transport, and disputes between Russia and Ukraine have led to shortages in some EU countries (but not the UK), although the increasing role of liquefied natural gas gives the UK more options. In the USA, new production techniques have created a boom in previously inaccessible shale gas and reduced that

country's imports, increasing the amount of gas available to European countries – which may exploit their own reserves in due course. The UK has its own shale gas reserves, recently estimated to be in the top 20 internationally⁹¹ – the question is, over and above the environmental concerns, how much can be extracted at a cost which makes it worthwhile?

Electricity is expensive to store (the capacity of the UK's pumped storage hydro stations is limited) and must therefore currently be generated when it is required. This means that power stations must not only exist, but must be available at particular times, and the industry should always own more capacity than the expected peak demand. In the past, a capacity margin of 15% has been seen as adequate, although the CEGB's planners worked to a much higher margin when deciding (seven years ahead) how much plant to build, in case demand grew faster than expected. It is rare for many fossil-fuelled power stations to be out of action simultaneously, but an area of low winds could cover the UK, creating a significant risk that a large number of wind farms could provide very little electricity at a time of high demand. This means that increasing the amount of wind capacity may not allow for a significant reduction in the amount of other generating capacity, even though a large number of the power stations kept open will not run very often,⁹² without greater interconnection or smarter electricity management systems.

The supply of uranium is unlikely to pose a major risk to energy security over the next few decades. It is mined in a number of politically stable countries (including Australia and Canada) and the relatively small volumes required make it easier to stockpile than coal, oil or gas. The biggest risk to energy security

from nuclear power concerns the possibility of a forced shut-down of a large number of nuclear plants on safety grounds. This might come about if a large number of reactors share the same design, and this is revealed to have a generic fault requiring urgent repair, as occurred in Japan in 2002, or if a nuclear accident (in the UK or elsewhere) leads to a political decision to shut down nuclear plants, as happened in Germany and Japan after Fukushima. Carbon capture and storage might be subject to similar risks if leakage or an accident in the transportation system led to the release of a large amount of carbon dioxide, which is heavier than air and presents serious safety concerns when concentrations rise above a few percent.

Nuclear power also has implications for security in the more general sense. The technology needed for civil nuclear power is related to that required for nuclear weapons – as nuclear power spreads around the world, the number of states able to make nuclear arms could increase. Nuclear fuel and nuclear waste could also be used by terrorist groups, and must be guarded appropriately. One means of reducing this risk would be to create an internationally-controlled nuclear fuel bank. Another would be to give priority to nuclear technologies which were more proliferation resistant – though no nuclear technology is 100% proliferation resistant.

2.4 Cost

It is impossible to know whether building nuclear power stations will increase or decrease the cost of the UK's electricity supplies relative to alternative options. Government commissioned reports from engineering consultants⁹³ imply that future nuclear power stations would be cheaper

than (or equivalent to) gas- or coal-fired plants or offshore wind power but these predictions depend on forecasts of future fuel and carbon prices. The EDF 2010 estimate for construction of twin EPR reactors was £4.5b. However, it is reported that EDF has recently revised these cost upwards⁹⁴ indicating that construction costs may be closer to £7b, which will also have consequences for the eventual cost of electricity. In any case, it is not always helpful to concentrate on predicting the cost of running one particular power station (the standard way in which costs are presented), for a large number of stations have to work together to meet demand. While the standard calculation gives the cost for a base load power station running for 85% or 90% of the time, many stations will be required to run for shorter periods to meet the peaks in demand. Nuclear power stations are well suited for base load operation, since their variable operating costs are low; once the (high) cost of building them has been incurred, so it is best to use them as much as possible. If a nuclear power station was only used in the winter (when electricity demand in the UK is highest), its average cost would be much greater, since the high fixed costs would be spread over a relatively small level of output. If we need to build capacity just to meet the peaks in demand, it is best to build plants with a relatively low capital cost, even if this means accepting a much higher operating cost, since there will be relatively few hours of operation. It is also best to build plants which can be turned on and off quickly and easily. Both these factors point to gas stations as the most suitable back-up capacity to mitigate the variability in demand and wind power. It should be noted, however, that gas produces CO₂ emissions and in a bid to limit greenhouse gas emissions this presents additional issues.

⁸⁶ International Atomic Energy Agency (2011): 'Nuclear Power Reactors in the World, Reference Data Series No. 2' IAEA: Vienna http://www-pub.iaea.org/MTCD/Publications/PDF/RDS2_web.pdf and BP: (June 2011) 'BP Statistical Review of World Energy' BP: London http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/pdf/statistical_review_of_world_energy_full_report_2011.pdf

⁸⁷ Sir Christopher Hinton, Chairman of the Central Electricity Generating Board, giving evidence for Select Committee on Nationalised Industries (1963). Reference – House of Commons, Select Committee on Nationalised Industries (1963): 'Report from the Select Committee on Nationalised Industries: The Electricity Supply Industry' HC 236 of 1962/3, HMSO: London

⁸⁸ Haszeldine, S. (2006): 'Response to Treasury Consultation on Carbon Capture and Storage' UK Energy Research Centre (UKERC): London http://www.geos.ed.ac.uk/research/subsurface/diagenesis/UKERC_Treasury_CCS_consultation_v_3_2_May06.pdf

⁸⁹ Parliamentary Office of Science and Technology (October 2006): 'Postnote Number 268: Carbon Footprint of Electricity Generation' <http://www.parliament.uk/documents/post/postpn268.pdf>

⁹⁰ It should be noted that coal ash is also radioactive, though its disposal does not present the same issues.

⁹¹ Gloystein, H. and Johnson, C (2012): 'Exclusive – UK has vast shale gas reserves, geologists say' Reuters, April 17th 2012 <http://uk.reuters.com/article/2012/04/17/uk-britain-shale-reserves-idUKBRE83G0KS20120417>

⁹² Europe's leading electricity trade association, Eurelectric, suggested in a 2011 publication entitled 'National Renewable Energy Action Plans: An industry analysis' that an electricity system with half of its electricity generated by intermittent renewables would require almost as much conventional capacity as would a system with no renewable capacity at all.

⁹³ Mott MacDonald (2010): 'UK Electricity Generation Costs Update' Mott MacDonald: Brighton <http://www.decc.gov.uk/assets/decc/statistics/projections/71-uk-electricity-generation-costs-update-.pdf>; Parsons Brinckerhoff, for DECC (2011): 'Electricity Generation Cost Model – 2011 Update Revision 1' Parsons Brinckerhoff: London http://www.pbworld.com/pdfs/regional/uk_europe/decc_2153-electricity-generation-cost-model-2011.pdf

⁹⁴ Reuters (8 May 2012): 'UK nuclear build requires taxpayer rescue – Citi' <http://uk.reuters.com/article/2012/05/08/uk-nuclear-britain-edf-idUKBRE8470XC20120508>

A more appropriate measure (though more involved) is to calculate and compare the cost of running two portfolios of power stations, one including nuclear power and one without. But such estimates still depend on predictions of the price of gas – inherently unpredictable – and of the cost of building a nuclear power station in the UK, where none has been built for almost 20 years. The first stations of a new programme ('first of a kind') will almost certainly cost more than the following ones ('n of a kind') – the supply chain will need to be developed, workers trained and designs finalised. Because of the uncertainty over exactly what they will cost, the early stations will have to be financed with a higher proportion of risk-bearing equity and a lower proportion of (cheap) debt.

In contrast, gas-fired combined cycle gas turbine stations are a mature technology with little construction risk. The cost of building an onshore wind turbine is also predictable, although the time and expense involved in getting planning permission is not. Building wind turbines far offshore is much riskier, and the cost of near-shore turbines has failed to fall as expected. Carbon capture and storage also involves significant technical and construction risk at present, until full-scale systems have been shown to work.

All power stations need to be decommissioned at the end of their working lives, but the cost of dealing with nuclear waste and spent fuel makes this a much greater expense for nuclear stations. It is an expense that will not need to be paid out for decades, however, which means that relatively modest contributions during the station's operating life, if set aside and allowed to earn interest, can build up to a sufficient fund. One problem that kept the nuclear stations out of the privatisation of 1990–1 was that no separate decommissioning fund had been built up, and a special levy was instigated during the 1990s to create one.

While the price of uranium and of fuel processing may move up and down, it is a small part of the total cost of nuclear energy (10–20%). In contrast, the price of gas has a significant impact on the cost of gas-fired generation. This means that once a nuclear station has been built, it faces relatively low

cost risks, as long as its technical performance meets expectations. In a power system where prices are linked to the average cost of generation, such as the regulated companies in many parts of the USA, this means that the presence of nuclear power stations will make prices less variable. In the UK, however, the price of power is set in a wholesale market and linked to the cost of the most expensive stations needed to meet demand, typically those burning gas. Adding some nuclear power stations to the system will not change this. Prices to consumers still go up and down with the cost of gas.⁹⁵ This also means that a nuclear power station which sells at the same wholesale price will face a significant risk to its profits – when gas prices are high, the station could be highly profitable, but a low gas price would mean that its revenues fell below its costs. It was during a period of low gas prices that British Energy had to be rescued by the Government. It is worth noting that the present glut of shale gas in the US has resulted in particularly low gas prices. Under the proposed electricity market reforms (EMR) some of the sensitivity to gas prices will be removed.

2.5 UK Energy Policy

Following electricity privatisation, the UK Government followed a market-led energy policy, working on the assumption that companies following signals from the market would generally make the best decisions for the country. There were small-scale schemes to promote energy efficiency, and a series of auctions to commission renewable generation under the so-called Non Fossil Fuel Obligation. The 1995 White Paper that led to the privatisation of British Energy made it clear that the Government was not about to promote the building of more nuclear power stations. Following the 1997 election, the Labour Government intervened more, changing the way in which electricity was traded and attempting to slow the rate at which gas-fired stations were replacing coal. It also scaled up support for renewable energy, creating a system of Renewables Obligation Certificates which energy retailers had to buy from the generators, giving them a premium over the wholesale price. And Labour's 1997 manifesto took a strongly anti-nuclear line.

During its 13 years in power, Labour gradually moved to a pro-nuclear position. In 2003, the Government issued an Energy White Paper that set a target of reducing the UK's carbon emissions by 60% (relative to 1990 levels) by 2050. It did not 'propose to set targets for the share of total energy or electricity supply to be met from different fuels.' The White Paper noted that the 'current economics [of nuclear power made] it an unattractive option for new, carbon-free generating capacity and there [were] also important issues of nuclear waste to be resolved.' It did 'not contain specific proposals for building new nuclear power stations. However [the government did] 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.'⁹⁶

A few years later, however, there was another energy review, against a background of higher fossil fuel prices and a rapid decline in the UK's output of oil and gas. The Stern Review on the economics of climate change, published in 2006, had set out an economic case for taking early action to reduce carbon emissions and, indeed, spelt out in harsh economic terms the consequences of 'do nothing' and of the global impact of implementation delays. The 2006 Energy Review included an explicit consultation on policy towards nuclear power. The Energy White Paper issued in May 2007 announced that the Government would adopt legally binding targets for carbon emissions, and increased the future targets for renewable generation. The White Paper also announced that it was the Government's 'preliminary view... that it is in the public interest to give the private sector the option of investing in new nuclear power stations.'⁹⁷ This could only be a preliminary view, however, for the Government had lost a judicial review, sought by Greenpeace, on the basis that ministers had made overly pro-nuclear statements during the consultation period, thereby prejudicing its result.

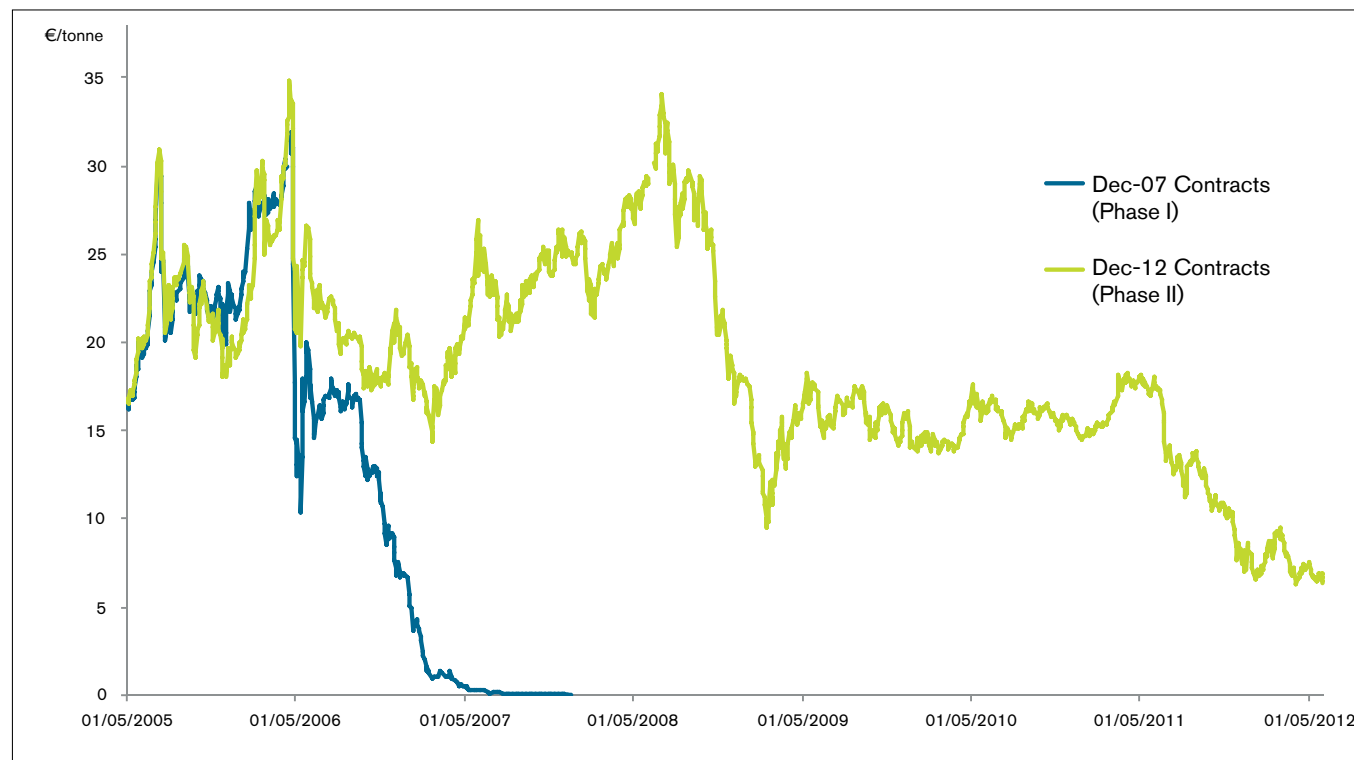
The new policy was announced in January 2008. 'The Government believes it is in the public interest that new nuclear power stations should have a role to play in this country's future energy mix alongside other low-carbon sources; that it would be in the public interest

to allow energy companies the option of investing in new nuclear power stations; and that the Government should take active steps to open up the way to the construction of new nuclear power stations. It will be for energy companies to fund, develop and build new nuclear power stations in the UK, including meeting the full costs of decommissioning and their full share of waste management costs.⁹⁷ The White Paper set out the active steps envisaged, which included (already announced) reforms to the planning process intended to separate site-specific issues (properly the province of a public enquiry on a specific proposal) from more general issues of energy policy. In particular, the nuclear safety and environmental regulators were to start a process of Generic Design Assessment (GDA) which would provide information on the acceptability (in terms of safety and environmental impact) of particular reactor models and 'limit the need to discuss the issues in depth during the site-specific licensing process'.⁹⁸

The EU has also been active in energy policy. The EU Emissions Trading Scheme⁹⁹ (ETS), which came into force in 2005, requires generators (and some other large users of fossil fuels) to have a permit for every tonne of carbon dioxide that they emit. If the permits are expected to be scarce, they will be expensive and generators will have an incentive to use lower carbon fuels. Generators were given large numbers of permits in the first two phases of the scheme (from 2005–7 and from 2008–12). From 2013 they will have to buy permits at auction. The giving out of permits reduced the impact of the ETS, but the ETS should still have created the incentive to shift towards lower carbon generation, since generators had the option of selling their unwanted permits. The initial allocations for 2005–7 turned out to be so generous, however, that 'business as usual' emissions were lower than the number of permits

available, and their value fell to zero. The allocations for 2008–12 were tighter, but when European economies went into recession after the financial crisis of 2008, worsened by the subsequent problems of debt in the Eurozone, they too proved to be little tighter than business as usual demand, and permit prices fell again. In April 2012 they were around €7/tonne of carbon dioxide, compared to the European Commission's expectation at the time when it set the caps for the post-2013 phase of around €30/tonne. The ETS has done what it was (formally) required to do, which is to ensure that the EU's emissions (from installations covered by the scheme) are below the target level, but it has not set and sustained a price for carbon at a level that would provide a strong incentive to invest in low carbon generation.

Figure 1: European Emissions Allowance Prices (Euros per tonne of carbon dioxide). Source: European Carbon Exchange.



⁹⁵ Increases in the price of gas were responsible for more than half of the increase in the cost of electricity to domestic consumers between 2004 and 2010, according to the Committee on Climate Change (2011) 'Household energy bills – impacts of meeting carbon budgets', Committee on Climate Change: London http://downloads.theccc.org.uk/s3.amazonaws.com/Household%20Energy%20Bills/CCC_Energy%20Note%20Bill_bookmarked_1.pdf

⁹⁶ Department of Trade and Industry (2003) 'Energy White paper: Our Energy Future – Creating a Low Carbon Economy' Cm 5761, The Stationery Office: London, paragraphs 1.21 – 1.24 (parts). <http://webarchive.nationalarchives.gov.uk/+http://www.berr.gov.uk/files/file10719.pdf>

⁹⁷ Department of Trade and Industry (2007): 'Meeting the Energy Challenge – A White Paper on Energy' Cm 7124, The Stationery Office: London, page 18. <http://www.berr.gov.uk/files/file39387.pdf>

⁹⁸ Department for Business Enterprise and Regulatory Reform (2008) 'Meeting the Energy Challenge – A White Paper on Nuclear Power' Cm 7296, The Stationery Office: London, paragraph 1. <http://webarchive.nationalarchives.gov.uk/+http://www.berr.gov.uk/files/file43006.pdf>

⁹⁹ Now formally called the Emissions Trading System http://ec.europa.eu/clima/policies/ets/index_en.htm

The EU's other major energy policy is to require its members to adopt targets for the share of renewable energy in 2020 which add up to 20% of the EU's final energy demand. The UK's target is for 15%, for it has started from a very low base. The EU does not lay down how member states should meet their targets; the UK's Low Carbon Transition Plan suggests that around 1/3 of our electricity would come from renewables, were we to meet the target in the most cost-effective manner.¹⁰⁰ The EU also allows member states to choose their own policies for supporting renewable energy, although it has stated that '*well-adapted* feed-in tariff regimes [were] generally the most efficient and effective support schemes.'¹⁰¹

The UK had been using a different policy to support large scale renewable generators, although it introduced a feed-in tariff for generators with a capacity below 5 MW in 2010. At the end of that year, the new Coalition Government started to consult on a package of changes to the arrangements for larger generators, which has become known as Electricity Market Reform. The Government plans to impose an Emissions Performance Standard which would prohibit generators building coal-fired power stations without (at least some) carbon capture and storage. A Capacity Market will provide a more secure revenue stream to the stations needed to offset the variability of wind power output. A new tax, the Carbon Price Support, will be imposed at a rate calculated (each year) to bring the sum of the tax and the carbon price in the ETS to a pre-determined level. From 2013, electricity generators will have to pay £16 for every tonne of carbon dioxide they emit, moving to £30 by 2020. This level has been calculated to make investment in low carbon generation attractive (and had been specifically requested by EDF energy as the tool necessary to build new

nuclear stations in the UK), although its profitability would still depend on the price of fossil fuels. To avoid this uncertainty, the final element of the package is a new support instrument, a so-called 'feed-in tariff' with 'contract for differences'.

The aim of the FiT-CfD is to combine the price guarantee of a feed-in tariff with the incentives given to a power station that has to sell at market prices. Nuclear stations will be offered a contract that pays the difference between a pre-determined strike price and the eventual price of electricity over the period for which the contract is valid. For nuclear stations, this out-turn price will probably be based on the cost of a contract for baseload (continuous) power sold one year in advance. If the station sells its output through this kind of contract and the market price turns out to be lower than the pre-determined strike price, extra payments under the contract will make up the difference. This provides insurance against low prices. At the same time, the station has to sell its output in the market and can respond to market signals on the true value of its power, which is not the case for the standard feed-in tariff, paying the same amount whether electricity is needed or not.

Many details of the contracts are still to be worked out, including, perhaps most importantly, how the prices are to be set. Many Liberal Democrats would be reluctant for the price of the FiT-CfD to be set above the expected future level of electricity prices, as this would imply that nuclear energy was being subsidised. Carbon Price Support will raise the price of electricity, and thus make it less likely that any given price for a FiT-CfD does in fact imply a subsidy. The package may thus meet a mix of political and economic constraints. The Conservative-Liberal Democrat coalition

agreement explicitly stated that new nuclear stations would be supported, but that there would be no subsidy. But Energy and Climate Secretary Chris Huhne told delegates at his own Liberal Democrat party conference in 2012¹⁰² that nuclear was a necessary part of the low carbon mix, and in media interviews said only that there should be 'no specific subsidy'¹⁰³ to nuclear. Most Liberal Democrat party members remain anti-nuclear, although the number of pro-nuclear Liberal Democrats is increasing. Labour remains pro-nuclear under Ed Miliband.

Recommendations

- **Estimates of the cost of electricity should emphasise the cost of the system as a whole, as well as that of individual stations.**
- **Consideration needs to be given to the system requirements of both a high – larger than 30% – renewable energy share and large nuclear baseload capacity.**
- **The Government should rapidly provide details of the contracts for its feed-in-tariff with contracts for differences (fit with CfD), to help investors make decisions.**

¹⁰⁰ There are significant complexities in delivering an energy mix made up of substantial contributions of nuclear energy and renewable. Nuclear is not flexible and renewable is highly intermittent requiring backup capacity – which is likely to be from gas powered stations.

¹⁰¹ European Commission (2008): 'The Support of Electricity from Renewable Energy Sources. Accompanying document to the Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources'. Commission Staff Working Document SEC(2008) 57, Commission of the European Communities: Brussels, page 3. http://ec.europa.eu/energy/climate_actions/doc/2008_res_working_document_en.pdf

¹⁰² Nuclear Industry Association Supply Chain News: 'Huhne backs new nuclear at Lib Dem conference' <http://www.nuclearsupplychain.com/scnews/138-huhne-backs-new-nuclear-at-lib-dem-conference>

¹⁰³ <http://www.telegraph.co.uk/earth/energy/8205123/500-on-electricity-bills-to-pay-for-green-energy.html>

3

New nuclear stations in the UK

Since the 2008 White Paper, UK government policy has been to ‘take active steps to open up the way to the construction of new nuclear power stations.’¹⁰⁴ However, it would ‘be for energy companies to fund, develop and build’¹⁰⁴ those stations.

This chapter asks whether conditions are right for a new generation of nuclear power stations in the UK to go ahead. This question can be broken into three parts: i) the Government and its regulatory agencies must be in a position to give consent to a new development; ii) the developer must decide to go ahead with the project, with a suitable business case and finance available; iii) Industry in the UK must be capable of building the station. We examine each of these parts in turn.

3.1 Background

Since the 2008 White Paper, UK government policy has been to ‘take active steps to open up the way to the construction of new nuclear power stations.’¹⁰⁴ However, it would ‘be for energy companies to fund, develop and build’¹⁰⁴ those stations. This chapter asks whether conditions are right for a new generation of nuclear power stations in the UK to go ahead. This question can be broken into three parts: i) the government and its regulatory agencies must be in a position to give consent to a new development; ii) the developer must decide to go ahead with the project, with a suitable business case and finance available; iii) industry in the UK must be capable of building the station. We examine each of these parts in turn.

3.2 The Role of the Government

There is currently a broad political consensus in favour of nuclear energy, at least as measured by the official policies of the three main UK-wide parties. The 2008 White Paper committed the Labour Party to nuclear new build, and the Coalition Agreement of 2010 was agreed by the Conservatives and the Liberal Democrats. It is worth noting that many Labour and Liberal Democrat activists may be anti-nuclear, however, along with a significant proportion of the general public. While the front-bench consensus appears firm at present, it should be noted that governments can sometimes change their mind on nuclear power. The response of the German Government to the Fukushima disaster, closing seven nuclear reactors immediately and reducing the lifetimes of another nine, is an obvious example which actually came shortly after Chancellor Merkel’s government had reversed the early closures ordered by its predecessor. A serious nuclear accident in Western Europe, however unlikely, might put the UK’s current political consensus at risk. A strong swing in public opinion is something that many politicians would find hard to resist. Witness the Japanese situation where in early May 2012 no reactors are in operation.

It is hard for a democratic government to bind its successors. Payments for electricity produced by nuclear power stations can be arranged through long term contracts which a court would enforce. A contract that committed the Government (or electricity consumers) to make payments, even if a subsequent government decision meant that the station was no longer producing any power, might be politically unacceptable. We doubt that there is any practical step that the UK Government could take to insure nuclear developers against the consequences of a future change in nuclear policy.

UK government decisions must be consistent with European Union rules. The most important of these concern state aid for industry. The European Commission has attempted to take a larger role in nuclear safety regulation – following the Fukushima disaster, national regulators were required to ‘stress-test’ their approach to regulation and the reactors in their territories.

The 2008 White Paper sets out a procedure for giving permission for new stations. First, the Government would have to decide that there was a national need for more nuclear power stations. This was part of a procedure established under the Planning Act 2008,

¹⁰⁴ Department for Business, Enterprise & Regulatory Reform (2008): ‘Meeting the Energy Challenge. A White Paper on Nuclear Power’ TSO (The Stationery Office): Norwich <http://webarchive.nationalarchives.gov.uk/+http://www.berr.gov.uk/files/file43006.pdf>

intended to focus planning decisions on local issues, rather than debating the national need for a particular kind of installation on every occasion that one was proposed. The new procedure should reduce the time and cost taken up by planning inquiries, while the National Policy Statements were to be debated in, and approved by, Parliament, maintaining democratic accountability. Six statements on energy infrastructure were approved in July 2011. The National Policy Statement for Nuclear Power Generation¹⁰⁵ instructs the planning authorities to assess applications for consent to build nuclear power stations on the basis that the need for them has been demonstrated. The statement also reported on the results of a Strategic Siting Assessment, which listed eight sites nominated by would-be developers as potentially suitable for new nuclear stations. Each of these was very close to an existing (or closed) nuclear station. Three other sites were rejected as unsuitable. The procedure allows developers to propose building a new station on a site which is not on the approved list, but doing so would clearly involve delays while a further assessment was made. At a similar time the Scottish Government's policy was to migrate away from a dependence on nuclear power.¹⁰⁶

Another step for nuclear power stations is that the Secretary of State has to issue a Regulatory Justification under the UK's laws on activities involving radiation to comply with the EU Basic Standards Directive. Statements were issued in October 2010 for the two main designs of nuclear power station proposed by developers, the Westinghouse AP 1000 and the Areva EPR. In each case, the statement concluded that the benefits from any station of this kind would outweigh any radiological health detriments that it might cause. Once again, the House of Commons approved these decisions by a very large majority, and these were implemented in the form of statutory instruments,¹⁰⁷ in November 2010.

Nuclear safety regulators (the Health and Safety Executive's Office for Nuclear Regulation and the Environment Agency) have also been conducting a Generic Design Assessment (GDA) for each of these designs. This is intended to assess the acceptability of a proposed design for a nuclear power station, before its suitability for a particular site is considered in the planning process. Four companies submitted designs for assessment in July 2007 – as well as the AP1000 and EPR, Atomic Energy of Canada Limited (AECL) and GE-Hitachi Nuclear Energy submitted proposals. The GDA process started with

a high level assessment, which all four designs passed, but AECL withdrew its design before work started on the next, more detailed, stage. GE-Hitachi suspended their application a few months later, in September 2008. None of the consortia proposing new stations in the UK were planning to build either type of plant.

The GDA process is iterative, both in the sense that the regulators start with an overview of the reactor designs and then consider more detailed issues of system design and evidence for safety, and in the sense that the companies are given opportunities to respond to the regulators' concerns. At the time of writing, both reactor designs have been given interim design acceptance. Some issues remain to be resolved, and a reactor cannot be built in the UK before the regulators are satisfied that they have been, but the regulators were satisfied with the companies' approach to resolving each of these. Overall, the process of gaining government and regulatory approval for building new nuclear power stations in the UK appears to be going smoothly.

3.3 Company Decisions to Invest in New Nuclear Energy

Three consortia have shown an interest in building new nuclear power stations in the UK. EDF Energy has set up a consortium with Centrica to build new stations through a company known as NNB Genco. Two subsidiaries of German companies, E.ON UK and RWE npower, set up Horizon Nuclear Power. Both parent companies operate nuclear reactors in Germany. A third consortium, NuGen, contained Iberdrola of Spain, GDF Suez and Scottish and Southern Energy. Iberdrola and GDF Suez operate nuclear reactors in Spain and Belgium, respectively.

Scottish and Southern pulled out of the NuGen consortium in September 2011, saying that it wished to concentrate on developing renewable energy, in which it had greater expertise. Its stake was bought by its partners, Iberdrola and GDF Suez, which now each own 50% of the consortium. RWE and E.ON announced in March 2012 that they had decided to sell their joint venture, Horizon Nuclear Power, with its plans to develop two nuclear sites. RWE's press statement explicitly linked the decision to the German Government's phase out of nuclear energy. The company had responded to this by divesting assets and reducing its capital expenditure. In April 2012, the *Financial Times*¹⁰⁸ reported that

Centrica had told the Government that it was likely to withdraw from its consortium with EDF Energy unless it received assurances on the future price of nuclear energy.

Nuclear power stations are large and capital-intensive. A company that invests in nuclear energy must commit a large amount of money for a long period. It needs to believe that there is a more than reasonable prospect of getting that money back, together with a return that compensates for the risks involved. The higher the risks, the higher the return that the company – and its investors – will seek.

Most existing reactors were built by companies under (explicit or implicit) systems of regulation that allowed them to pass their costs on to consumers, who had no choice over where they bought electricity. This model minimised the risks to the company, keeping down its cost of capital, although incentives for companies to keep their costs down were correspondingly weak. Since 1990, the UK (like many other countries) has liberalised its electricity industry, allowing many different companies to compete to sell electricity in a wholesale market that sets prices on the balance of supply and demand. This has provided strong incentives to keep costs down, but also raises the risks of investment.

The price of electricity depends on the cost of the fuel used by the plants with the highest variable costs (generally gas) and on the amount of spare capacity – the lower the capacity margin, the higher the market price. All generators are exposed to risks over the capacity margin (the industry, like many others, tends to have cycles of investment and prices). Fuel price risk does not affect every technology in the same way. If the price of fossil fuels is low, this will depress the price of electricity, but nuclear (or other low carbon) stations will still have to service their debts. Gas-fired plants may be less affected by this (depending on how far ahead the gas is purchased) because their revenues and costs may move together.

Finland is part of the Nord Pool electricity market, where the price of power varies with fuel prices and the amount of water available to Scandinavia's hydro stations. Nonetheless, the Olkiluoto 3 plant was financed, by a consortium of energy-intensive industrial consumers that wanted a long term supply of power at a fixed price and were prepared to make a corresponding commitment to develop a nuclear station. There is no sign that the UK contains a similar group of industrial energy users able to underwrite a similar deal.

To reduce the risks for nuclear energy (and other low carbon generators) the UK Government is going to reform the electricity market, introducing a feed-in tariff with contracts for differences (FiT with CfD).¹⁰⁹ This has the potential to fix the nuclear station's revenues at a level sufficient to cover its costs, regardless of swings in the wholesale price of power. The feed-in tariffs used for renewable power in Europe (including for small-scale generators in the UK) pay a set price for all the output from a station, giving it no incentive to respond to market signals, for example by scheduling maintenance at times of relatively low demand. The proposed arrangements for nuclear energy aim to preserve some market signals, in that the stations will have to sell their output into the wholesale market, and will receive a price reflecting its market value at the time of the sale. However, the CfD part of the arrangement ensures that the station will also receive, or make, payments based on the difference between a strike price specified in the contract and the market price for the kind of power that the station is selling – how this is measured will also need to be specified in the contract. In the case of nuclear stations, this market price will probably be the price for a year's continuous supply of power, sold shortly before the start of the year. It will not be the actual price received by the station – guaranteeing the actual revenues received could create perverse incentives – and so the station still has to find a buyer for its power and operate in a way that the buyer wants. However, as long as the station can sell its power at a price close to the market price, the sum of what it gets from doing so and the side payment should be nearly constant.

This has the potential to greatly reduce the financial risks from operating a nuclear power station in the UK. Once the stations are commissioned, they could benefit from a low cost of capital, and it might be possible to finance them with a high proportion of debt.

Even so, the consortia will not be able to make a final investment decision to build a new station (and may be reluctant to spend much money preparing to do so) until they know exactly how the contracts will work. It is not yet clear who the counter party to the contract will be (possibly the National Grid), and how their finances will be guaranteed. Investors will get little security from holding a contract with a company that they believe might become bankrupt. In the end, the contracts will be financed by electricity consumers, but water-tight arrangements are needed to ensure that their payments end up with the nuclear operators.¹¹⁰

□ **We recommend that the Government clarifies the terms of its FiT-CfD contracts as soon as possible, and has robust arrangements to make them acceptable to the parties who will have to finance new nuclear investments.**

The other significant risk facing a nuclear developer is construction risk – how much will the station cost, and how long will it take to build? (Even if a delay in construction did not involve additional payments to the builder, the developer would still have to pay interest on its debts for a longer period before it started to receive any revenues, adding significantly to its overall costs.) We address measures to mitigate these risks below, but the question here is how they affect the decision to invest.

For the first of a kind nuclear plant, the risks are particularly acute – there is no experience of building a station in UK conditions that would allow more accurate cost estimates. Gas-fired power stations can be project financed – the parent company (or joint venture) sets up a subsidiary to build and run the station, financed with a mix of debt and of equity – money put in by the parent(s). If the project is risky, the proportion of equity and the interest rate on the debt will be higher than if the project is

regarded as safe. Gas-fired projects can reduce their risks with matching contracts to buy gas and sell power (at prices that leave a suitable profit margin) and guarantees about the cost and performance of the power station, provided by a builder with the experience (and financial resources) to make these credible. No credible cost and performance guarantees could be provided for a first of a kind nuclear power station. The parent companies of the UK's nuclear consortia will need to invest a large amount of equity, providing a cushion that gives lenders confidence that their money can be repaid, even if things go wrong in the construction phase. It may well be necessary for the parents to guarantee the consortium's debts. This would support each project with the full strength of the parent companies' balance sheets. Unfortunately, the costs of a nuclear power station are such that even a strong balance sheet may not be able to support more than a few projects. Europe's financial markets are not working well in 2012, in terms of delivering finance for investment in physical assets.

One feature of many contracts (to build roads, schools or hospitals) under the Private Finance Initiative is that they were initially funded with a relatively high cost of capital, reflecting the significant risks involved at the construction stage. Once construction was complete, it was possible to re-finance the contracts at a much lower cost of capital, providing an immediate reward to the developer. On one view, this is simply the reward for bearing a risk that turned out well – had there been a significant cost over-run, there would have been no money available for a reward. A cost-plus contract might reduce the risks and the rewards, but could also reduce the incentive to control costs. For a relatively simple project, the incentive effects may be more important than trying to minimise the cost of capital.

¹⁰⁵ Department of Energy and Climate Change (2011): 'National Policy Statement for Nuclear Power Generation (EN-6)', The Stationery Office: London <http://www.decc.gov.uk/assets/decc/11/meeting-energy-demand/consents-planning/nps2011/2009-nps-for-nuclear-volumel.pdf>

¹⁰⁶ Scottish Government (September 2008): 'Energy Policy: An Overview' <http://www.scotland.gov.uk/Resource/Doc/237670/0065265.pdf>

¹⁰⁷ Department of Energy and Climate Change (2010): 'The Justification Decision (Generation of Electricity by the AP1000 Nuclear Reactor) Regulations 2010', The Stationery Office: London http://www.legislation.gov.uk/uk/si/2010/2845/pdfs/ukSI_20102845_en.pdf and Department of Energy and Climate Change (2010): 'The Justification Decision (Generation of Electricity by the EPR Nuclear Reactor) Regulations 2010', The Stationery Office: London http://www.legislation.gov.uk/uk/si/2010/2844/pdfs/ukSI_20102844_en.pdf

¹⁰⁸ <http://www.ft.com/cms/s/0/bb7f393c-8af0-11e1-912d-00144feab49a.html#axzz1wR2BJL2b>

¹⁰⁹ Contracts for difference is a contract in which a price for the electricity is pre-agreed and the if the market price for the electricity is less than the agreed price then the utility would receive the difference in price as compensation, alternatively if the market price is over the agreed strike price then the utility would pay the difference.

¹¹⁰ For example, if the payments from consumers are collected by an electricity retailer that goes bust before they can be passed on to the contract counter-party, who will make up the shortfall?

For nuclear power stations, it may be better to minimise the cost of capital, even if this involves reducing the incentive to minimise the construction cost. The way to minimise the cost of capital is to link the final price of electricity under the FiT with CfD to the cost of building the station. This might be achieved by an open-book approach to contracting, in which actual costs are passed through, rather than by attempting to fix a price which would inevitably include a high margin for error. The contracts should not ignore incentives – there should be modest payments for keeping to time and budget – but it is important to recall that real incentives are generally linked to risks.

3.4 Can the UK Build Nuclear Power Stations to Budget and on Time?

Due to the complexity of construction of large scale projects a realistic determination of the construction costs is challenging, especially a first of a kind (FOAK) project within the UK. More specifically the nuclear industry has a poor track record in terms of keeping projects within cost. In recent times the cost of the EDF EPR reactor at Flamanville, France, has seen costs rise at an annual rate which is 13% above Eurozone inflation.¹¹¹ Costs of the Darlington reactor in Canada were 70% over budget. In addition NDA's estimates of the decommissioning costs have risen from £47.9bn in 2002 to £103.9bn in 2011, rising at a rate of 4.2–6.0% above inflation.¹¹² The construction of the Olkiluoto 3 power plant in Finland has also encountered significant delays – it was due to be completed in 2009, but now is not expected to start operation until 2014. For many critics of nuclear energy it is this track record that stands in the way of a credible new build programme in the UK. However, the UK has been through the Generic Design Assessment process in advance of the build programme, which is something that was not performed in either Finland or France.

In recent years the UK has embarked on a number of large construction projects. These include the Olympic site and associated infrastructure, Terminal 5 at Heathrow, the Channel Tunnel Rail Link and the construction of Wembley Stadium. The Nuclear Industry Association 2008 report,¹¹³ provides an upbeat assessment of the last two and recognises that the lack of clear brief, in part, lay at the heart of the problems over the £760m construction of Wembley stadium. This ended up with wrangles with the contractors and changes in design. The most recent project, the construction of the London Olympics site,

has been completed on budget, on time and with an excellent safety record. It has been described as 'the biggest construction project in Europe and one of the biggest ever mobilisations of a nation's manpower outside a time of war.'¹¹⁴ The cost of the construction of the Olympic stadium is close to £500m and the total construction, including the other venues, £1bn. Based on the experience of Flamanville and Olkiluoto, the cost of constructing a new nuclear power station will be up to a factor of 10 higher than that of the Olympic Stadium. The example of the Olympics shows that successful civil engineering projects can be managed in the UK, but nuclear build is an order of magnitude higher in terms of cost and complexity.

In terms of new build in the UK, if the first project goes over budget and overruns in time then that will almost certainly see a loss in public confidence and curtailment of the programme. As such the construction of the first reactor will be seen as the litmus test of the ability of the nuclear industry to have learned past lessons. In this regard understanding the issues associated with the build of the EPR reactors at Flamanville and Olkiluoto is important. In the case of the latter, problems were found with the concrete in foundations, forgings were not up to standard, welding skills were inadequate and there were issues with a lack of understanding of standards.¹¹⁵ Subsequent EPRs at Taishan in China were started in 2009 and 2010 and construction is on course to be much faster than the Finnish and French experience,^{116, 117}. Similarly, construction of the AP1000 design reactors in China is also on schedule.¹¹⁸ The successful project management developed for these projects needs to be transferred to the UK new build programme.

Important in optimising any construction project is careful project planning and management – for example understanding the design in detail ahead of construction and not making non-essential adjustments/improvements during the construction phase. Such changes incur further safety reviews. In this regard the role of the Regulator is vital. It is also extremely important to firm up the final design and have rigorous change control.

In the UK the designs of the EPR and AP1000 have been reviewed extensively by the Office for Nuclear Regulation (ONR)¹¹⁹ and the Environment Agency¹²⁰ in what is called the Generic Design Assessment (GDA).¹²¹ In December 2011 the two designs were granted interim Design Acceptance

Confirmations (iDACs) and interim Statements of Design Acceptability (iSoDAs). These did not constitute final approval but the Regulators confirmed that they were satisfied with the plans of EDF and Westinghouse to resolve outstanding issues. It is this close upfront inspection which is likely to play an important role in the minimisation of uncertainties in the construction process. Such best practice should also be a key component of the licensing process associated with a Geological Disposal Facility (GDF).

In their report, the NIA highlight a series of criteria which would further minimise delays and cost overruns¹¹³:

- Ensure planning and regulatory approval procedures are streamlined and deliver fast-track resolution of any issues arising during the project and avoid interference once decisions are made.
 - Ensure documentation requirements and their approval routes are well understood by all.
 - Involve main contractors early and through collaboration with architect engineers, regulators and nuclear vendors; ensure that all parties understand what they have to deliver and under what terms and conditions.
 - Ensure that the supply chain is suitably qualified and experienced. Although the previous NIA studies have demonstrated that the UK can supply 70% to 80% of the power station, it is essential that companies are experienced and get themselves formally qualified for the scope that they are seeking and that they have the resources necessary to deliver on time.
- and
- Engage early with external and local stakeholders – be straightforward and up-front with people.
 - Learn from what was done well in other projects.
 - Avoid optimism fallacy – 'Our project won't encounter such difficulties'.
 - Hold collaborative workshops after award of contract, but before any manufacturing/site work starts, to review the design, to ensure understanding of the contract and to start teambuilding.
 - Establish strong controls and monitoring of programme and costs.
 - Ensure high level leadership that must be visible.
 - Success is carried forward by people.

Such principles provide excellent foundations for the new build programme.

- **Success of any major new build programme relies on the completion of the first reactor (likely to be at Hinkley Point) on time and within budget and with high levels of local engagement. This has to be followed by learning from experience from the FOAK construction, resulting in faster and less expensive construction – a fleet of reactors of the same design is the only way to achieve this. If the construction of the first reactor is problematic then the downturn in public support could see the premature termination of the entire programme. It is essential that lessons are learned from the construction of other similar reactors worldwide (eg, China and South Korea) and experienced project management is engaged.**

3.5 The Nuclear Supply Chain

It is estimated that the construction of new nuclear power stations in the UK will require an investment of the order of £40bn by 2025.¹²² This presents a number of opportunities but also potential challenges.

On the positive side there are tremendous opportunities for UK business to engage in the construction and the associated supply chain stimulating employment across the construction and engineering sectors. In the Nuclear Industry Association 2006 report¹²³ (updated in 2008¹¹³) it was concluded that

it should be possible for the UK to supply 70% of the components of a new nuclear plant. Further, it was believed that this could be increased to 80% with appropriate investment in facilities. It was recognised that large components such as the reactor pressure vessel and steam turbines could not be constructed in the UK and would need to be imported. At the 70% level this would imply that 'on the basis of a capital cost of £2m per MWe, UK orders worth more than £4,500m could conceivably be available for a twin unit EPR, and £3,500m for a twin unit AP1000.'¹²² A programme of 10 reactors would generate 64,000 person-years of employment.¹²²

The challenge is to realise this potential opportunity. For this to happen the capacity of business must be aligned with the high quality standards required by the nuclear sector. These standards are typically much higher than required elsewhere. Correspondingly, business needs to equip itself with facilities and training appropriate to the sector.

To this end the work done in developing the supply chain by the NIA has been essential (see <http://www.nuclearsupplychain.com/>). The development of a clear structure and strategy for business engagement involving a series of 'tiers' provides an excellent framework for engagement. Tier 1 (on a four-point scale) are the main project leaders (eg, for the delivery of the EPR to Horizon-Npower, AREVA, Balfour Beatty/Vinci and Siemens formed a Joint Venture). Tier 2 are a spectrum of companies typically already engaged with the nuclear industry and so likely to have already adopted the requisite working practices. Tiers 3 and 4

are typically companies from outside the nuclear sector, including SMEs, but whose area of expertise provides opportunity.

As to the question of whether the UK has the civil, electrical and mechanical engineering capacity to undertake a significant new build programme, it is estimated by the NIA that the demand would only amount to 2–3% of the civil and 4–5% of the mechanical and electrical engineering capacity of the UK¹²². As such it would seem that there should also be a sufficient degree of selectivity and competition.

The imperative for domestic, UK, engagement comes from the need for a substantial component of the build programme to be UK-based so that the economic benefit is felt. It would be a significant error if most of the funding were to go to overseas suppliers. Second, there is the significant opportunity to develop export opportunities. However, there is also the important question of whether UK companies can meet the stringent nuclear quality requirements.

There also exist potential pitfalls. In the building of new nuclear power stations it takes about five years to get to the point of construction and then a further five years to complete construction. The initial period includes licensing and the present Electricity Market Reform (EMR) process. Internal investment by companies to develop new facilities and skills requires certainty. Currently, there is very little certainty in this sector and the building of nuclear power stations, though likely, is not guaranteed. Hence, there will be a natural

¹¹¹ Source: EDF Investor Statements (2005–2011) <http://shareholders-and-investors.edf.com/news-and-publications/annual-reports-42724.html>

¹¹² Source: DTI and NDA (2002–2011) <http://www.greenpeace.org.uk/sites/files/gpuk/FUP-Subsidy-Report-Mar2011.pdf>

¹¹³ Nuclear Industry Association (2008): 'The UK capability to deliver a new nuclear build programme, 2008 Update' Nuclear Industry Association: London <http://www.niauk.org/images/stories/pdfs/supplement%20for%20web.pdf>

¹¹⁴ Ruddick, G: 'London 2012 Olympics: The Olympic Stadium made in Britain' The Telegraph, 16 Jul 2011 <http://www.telegraph.co.uk/finance/london-olympics-business/8641977/London-2012-Olympics-The-Olympic-Stadium-made-in-Britain.html>

¹¹⁵ World Nuclear News (16 October 2009): 'Olkiluoto pipe welding 'deficient', says regulator' http://www.world-nuclear-news.org/NN-Olkiluoto_pipe_welding_deficient_says_regulator-1610095.html

¹¹⁶ World Nuclear News (18 April 2012): 'Landmarks for new Chinese nuclear plants' http://www.world-nuclear-news.org/NN-Landmarks_for_new_Chinese_nuclear_plants_1804124.html

¹¹⁷ Energy Business IQ (Apr 17, 2012): 'AREVA Delivers EPR Reactor Components to Taishan Nuclear Power Plant' <http://nuclear-power.energybusinessiq.com/news/display.aspx?title=AREVA-delivers-EPR-reactor-components-to-Taishan-nuclear-power-plant-12647>

¹¹⁸ World Nuclear News (04 May 2011): 'Chinese nuclear construction continues apace' http://www.world-nuclear-news.org/NN-Chinese_nuclear_construction_continues_apace-0405115.html

¹¹⁹ Office for Nuclear Regulation. An agency of HSE <http://www.hse.gov.uk/nuclear/index.htm>

¹²⁰ Environment Agency <http://www.environment-agency.gov.uk/>

¹²¹ Office for Nuclear Regulation. An agency of HSE – Generic design assessment <http://www.hse.gov.uk/newreactors/guidance.htm>

¹²² Nuclear Industry Association (NIA): 'Nuclear Business Opportunities' <http://www.nuclearsupplychain.com/component/content/article/65>

¹²³ Nuclear Industry Association (NIA) (2006): 'The UK capability to deliver a new nuclear build programme' http://www.niauk.org/images/stories/pdfs/MAIN_REPORT_12_march.pdf

reluctance for Tier 3 and 4 companies to engage strongly. As a carrot, the recent Technology Strategy Board call¹²⁴ to provide funding to develop the nuclear power supply chain (which includes decommissioning) is designed to improve businesses' 'competitiveness, productivity and performance in the nuclear sector' and provides, through funding from the NDA, TSB, EPSRC and DECC, mechanisms for SMEs to engage. This is a modest, £15m, programme, and should be the first of several such steps to developing the UK skills base.

The recent freezing of the Horizon Nuclear Power plans to proceed with developing new nuclear power stations may also present challenges to UK engagement. EDF proposes to develop the Hinkley Point and Penly (in France) EPR reactors together. The procurement for both stations will be common.¹²⁵ There is a corresponding danger that a significant fraction of the supply chain for both build programmes will then be located in France.

Conclusions and Recommendations

- **For businesses to engage strongly and more widely with the opportunities in UK new build, certainty is required. Incentive schemes such as those offered by the TSB are needed to encourage SMEs to prepare for the opportunities in advance.**
- **The UK Government should ensure as part of the negotiations with the new build companies that the opportunities for UK business to engage in the new reactor build programme are maximised.**

In 2008 Sheffield Forgemasters was planning to extend their capacity to include very large forgings which would be appropriate for the nuclear new build programme. In order to expand its capacity to make it one of only two companies in the world capable of large scale forgings for the nuclear industry an £80m government loan was sought. This was initially awarded shortly before the 2010 election, and then withdrawn by the new Coalition Government,¹²⁶ which suggested that the financial markets might be the optimal route to financing the investment. Subsequently (2011) a loan of £36m was provided by the Government, but was to support smaller scale equipment investment¹²⁷ – in the belief that post Fukushima that demand for building new nuclear power stations internationally would decline. This was a decision made in the aftermath of Fukushima and it is possible that in the longer term energy economics and the relative attractiveness of nuclear energy in terms of cost and CO₂ footprint will cause many governments to return to nuclear new build. It is likely that short term interest has resulted in a lost opportunity for the UK to have major international impact.

Recommendation

- **The fact that the nuclear new build programme in the UK is likely to be in advance of that in many overseas countries means there exists potential for UK companies to place themselves in a strong position in terms of international supply-chains and exports – this opportunity should be maximised. The Government should recognise this through loans to key companies in the nuclear supply chain.**

Generating innovation in manufacturing is vital in the UK developing a competitive edge in international markets. In this regard nuclear manufacturing and engineering is no different. The development of a series of advanced manufacturing research centres across the UK is a potential vehicle for stimulating cutting edge manufacturing techniques. The establishment of the Nuclear Advanced Manufacturing Research Centre (NAMRC),¹²⁸ a University of Sheffield and University of Manchester joint venture, is important. This aims to target growth in manufacturing by gearing up the UK manufacturing supply chain to supply components for new nuclear build in the UK and overseas. Stimulated by this development, Rolls-Royce have announced that they are building a new nuclear manufacturing factory in Rotherham¹²⁹ and the AREVA/Rolls-Royce partnership for Rolls-Royce is to provide £400m components for the first wave of nuclear power stations.¹³⁰ The NAMRC has also formed the basis for the expansion of the National Skills Academy Nuclear (NSAN) into manufacturing.¹³¹ This highly developed focus which brings together universities, industry and skills development around high value manufacturing could in principle provide the much needed stimulus to place UK nuclear manufacturing in a leadership position.

¹²⁴ Technology Strategy Board (TSB): 'Developing the Civil Nuclear Power Supply Chain – Targeted Call for Knowledge Transfer Partnerships July 2012' The Technology Strategy Board: Swindon <http://www.innovateuk.org/content/competition/developing-the-civil-nuclear-power-supply-chain.ashx>

¹²⁵ Nuclear Industry Association (NIA) Nuclear Supply Chain (February 2011): 'The Essential Guide to the New Build Nuclear Supply Chain: Opportunities, Routes to Market, Codes and Quality Arrangements for Nuclear New Build in the UK, Stage One' Nuclear Industry Association: London http://www.nuclearsupplychain.com/images/stories/pdfs/EGUIDE_Feb_11/essential_guide_final.pdf

¹²⁶ BBC News, 17 June 2010: 'Sheffield Forgemasters' £80m nuclear parts loan axed' <http://www.bbc.co.uk/news/10341119>

¹²⁷ BBC News, 31 October 2011: 'Sheffield Forgemasters gets up to £36m from government' <http://www.bbc.co.uk/news/uk-england-south-yorkshire-15521707>

¹²⁸ Nuclear Advanced Manufacturing Research Centre (NAMRC) <http://namrc.co.uk/>

¹²⁹ BBC News, 17 February 2012 'Rolls-Royce deal boosts Rotherham nuclear jobs hopes' <http://www.bbc.co.uk/news/uk-england-south-yorkshire-17072533>

¹³⁰ Rolls-Royce (17 February 2012): 'Rolls-Royce and Areva strengthen nuclear co-operation' http://www.rolls-royce.com/nuclear/news/2012/120217_areva.jsp

¹³¹ National Skills Academy Nuclear (16th May 2012): 'Green Light For NSA Nuclear Expansion into Nuclear Manufacturing' <http://www.nuclear.nscademy.co.uk/news/green-light-nsa-nuclear-expansion-nuclear-manufacturing>

The UK nuclear fuel cycle:

historic, present and future

Although there is much discussion regarding the future role of nuclear energy in the UK, the choice of reactor technology, the number of reactors to build and the location of those reactors, the associated fuel cycle choices and challenges are often overlooked by commentators and the stakeholder community at large.

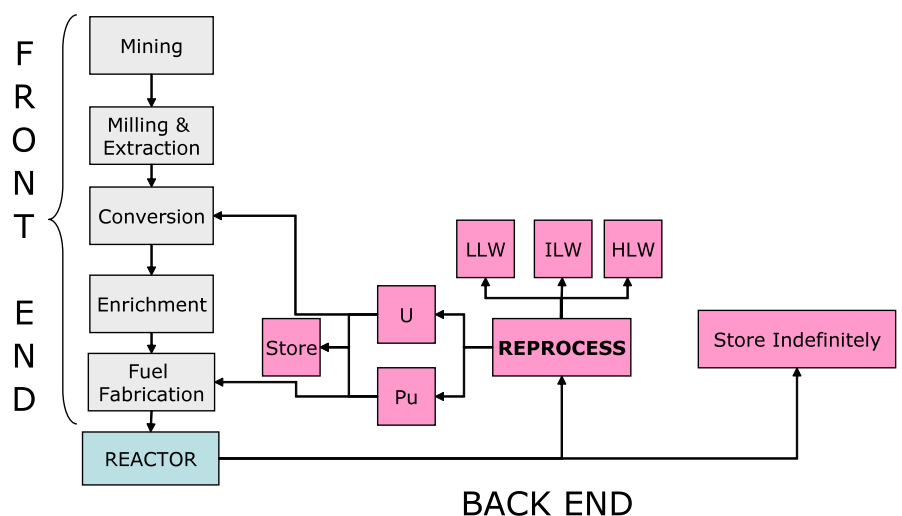
4.1 Background

The nuclear fuel cycle has an equally important role to play in the future choices and resulting challenges that the UK will face in deploying nuclear energy. There are many lessons to be learned for example from the historic choices, some good and some bad. Above all, a coherent, consistent and well thought out long term plan for any future UK fuel cycle has to be at the heart of the decisions taken by the operators, Governments and regulators. After all, any decision to proceed with a reactor technology and a given fuel cycle has implications, not just during the planning and operations phases of a new build programme, but for decades and centuries ahead and indeed the timing of the new build programme and the degree of the farsightedness of the nation will also govern which option(s) are selected. For example, if a once-through light water reactor (LWR) programme is chosen, then this could close off the potential future deployment of fast reactors for utilisation of the separated plutonium and minor actinides (MA).

4.2 What is the 'Nuclear Fuel Cycle'?

The term 'nuclear fuel cycle' refers to the sequence of processes in which nuclear material is handled before (front end), during (reactor operations) and after (back end) its use in a reactor for energy generation. Figure 2 shows a simplified schematic of the stages, starting with uranium mining.

Figure 2: Schematic of the Nuclear Fuel Cycle (store indefinitely includes geological disposal)



In order to minimise the volume of material needing to be shipped, the milling and extraction of the uranium ore (refining of the original ore body) is completed next to or nearby to the original mine (for example in Australia, Canada or Kazakhstan). However, the remainder of the front end of the fuel cycle has historically been, and still can be, completed in the UK at the Springfields site in Preston, Lancashire along with enrichment at Capenhurst in Cheshire. Every one of the Magnox fuel rods and Advanced Gas Cooled Reactor (AGR) fuel bundles has been manufactured in the UK since the reactors were built and hence fuel technologies were originally developed by the UK industry. However, in the case of the UK's only Pressurised Water Reactor (PWR), Sizewell 'B', after having the original fuel load made in the UK, the fuel is now manufactured in France or Germany. Since there are more than 270 PWRs out of approximate 430 reactors operating today, it is clear that the fuel supply for these reactors is based on a commodity supply basis, providing not only diversity in the designs, but also competition amongst the suppliers; this is one of the advantages of the UK moving to a truly international reactor technology.

Once the fuel has been irradiated in a given reactor and following a period of several years at the reactor for cooling in the storage ponds to allow the radioactivity and therefore the heat output to decay to manageable levels, there are then two options for handling the so-called 'spent' nuclear fuel:

- (i) **dispose** of the spent fuel indefinitely via direct disposal in a Geological Disposal Facility (GDF), which is known as the 'open fuel cycle'
- (ii) **reprocess** the fuel and recycle the reusable materials, known as the 'closed fuel cycle' (actually partially closed as a fully closed cycle would require fast reactors). Reprocessing is the method by which the unused, useful uranium and plutonium can be separated from the waste fission products and minor actinides and recycled for potential future re-use in new fuel.

The potential benefits of reprocessing and subsequent recycling of the plutonium and reprocessed uranium are that it reduces natural uranium requirements and considerably decreases the volumes of radioactive waste which have to be stored awaiting subsequent disposal.¹³² Reprocessing therefore enhances the sustainability of nuclear by reducing the use of natural uranium resources while ultimately

assuring improved waste management: typically 25% less uranium ore is required if the plutonium and uranium are recycled. However, there is international concern over the potential illegal use of reprocessing for non-civil purposes and therefore many countries are opposed to reprocessing for reasons of proliferation. Furthermore, with the abundance of uranium ore and relatively low uranium prices, the economic case for reprocessing is currently also difficult to make. In addition, the full potential benefit of reprocessing can also not be fully realised until fast reactors are commercially demonstrated and it becomes possible to recycle the minor actinides as well as the plutonium and uranium in order to assist the sustainability of nuclear energy. This is one of the areas under investigation as part of the international R&D effort on Generation-IV systems.

In addition to the recycled uranium and plutonium, the remaining waste streams from reprocessing are:

- High Level Waste (HLW), which is heat generating and contains the fission products and minor actinides. In the event that the spent fuel is not reprocessed, then it also is classed as HLW.
- Intermediate Level Waste (ILW), which is not significantly heat generating, for example mechanical components such as the cladding from the spent fuel.
- Low Level Waste (LLW), which is below a certain radioactive level, for example process waste such as paper and gloves.

These materials are then processed, packed and stored at Sellafield ready for final disposal. Currently, disposal of HLW and ILW is awaiting the decision on the location and design of the UK's GDF and the LLW is sent to the LLW Repository (LLWR) near Drigg in Cumbria and some specialist landfill facilities.

4.3 The Historic UK Fuel Cycle

Before reviewing the fuel cycle options that the UK has either deployed or is considering/has considered, it is important to note the range of reactor systems built and operated in the UK as this has driven the decisions over the fuel cycle(s).

The UK civil nuclear reactor programme began in 1953 when construction started of the first Magnox design at Calder Hall on the Windscale site in the far north west of England. It is important to recognise that these early Magnox stations were designed principally

to produce plutonium for the UK's nuclear weapons programme. As such, the separation of the plutonium from the spent fuel in some ways represented the start of the UK's first commercial fuel cycle. Following the early prototype stations at Calder Hall and Chapelcross in Scotland (each site with four units), a total of 18 further units were built in the UK. Following limited lifetime extensions, the Magnox reactors have continued to supply electricity to the national grid, with the closure of the final Magnox station at Wylfa due in 2014.

In 1964 the UK decided to develop advanced gas cooled reactor (AGR) technology to succeed the Magnox stations as the principal source of nuclear energy. This new reactor technology also represented a move to civil nuclear energy as the AGR reactors did not have plutonium production, but instead energy production as its main driver. Five AGR stations were built in England and two in Scotland. All of the AGRs are still operating today, generating approximately 8 GWe, with the first closure planned for 2016 and the last AGR expected to be retired in 2023, assuming no further lifetime extension beyond those already announced (typically five years extension to date with the potential for a further five years).

Construction of the UK's first (and to date, only) PWR, Sizewell 'B' in Suffolk, started in 1987. Electricity generation began in 1995 and without any lifetime extension, the plant is planned to operate until 2035, with a capacity of approximately 1.2 GWe. A lifetime extension until 2055 could be envisaged based on extensions for similar plants in, for example, the USA.

During the evolution of the UK nuclear programme, a variety of fuel cycles have been developed and deployed including reprocessing (with limited recycle of reprocessed uranium from Magnox and AGR reprocessing) and direct disposal of spent fuel, pending the GDF. As can be seen, a long-term strategy was never established and instead the UK has taken ad hoc decisions with no overall consistency.

In the case of Magnox fuel, the cladding degrades over time when stored under water (to allow cooling) and so all of the Magnox fuel must be reprocessed in a timely manner even though the plutonium from that fuel is no longer required for the UK weapons programme. For this reason, reprocessing of Magnox fuel continues today – but is a significant source of the UK's environmental radioactive discharge. In the case of AGR fuel, the commercial

contracts have altered over time such that all of the spent fuel generated by 2007 will be reprocessed, but the remainder will be ultimately disposed of in a GDF. Similarly, in the case of the PWR fuel for Sizewell 'B' all of the fuel will be stored pending disposal, with no reprocessing planned.

This 'mix' of fuel cycles will eventually result in a variety of materials and spent fuel forms (all figures are approximate)^{133, 134}:

- 100 tonnes of separated plutonium: approximately 80t from Magnox and 25t from AGR fuel
- 30,000 tonnes of uranium from Magnox reprocessing
- 5,000 tonnes of uranium from AGR reprocessing
- 25,000 tonnes of depleted uranium, a residue from the enrichment of the AGR and Sizewell 'B' fuel.
- 1,800m³ of vitrified and packaged HLW, 350,000m³ of packaged ILW and 40,000m³ of packaged LLW
- 3,500 tonnes of spent fuel from AGRs
- 1,200 tonnes of spent fuel from Sizewell 'B'

As can clearly be seen, having chosen different reactor types and fuel cycle options over the years, the UK finds itself with a variety of materials, waste products and spent fuel types, each with different processing and handling needs, which means different facilities, different challenges etc. Standardisation of reactor and fuel cycle options in the future will dramatically reduce the number of facilities required and thereby the operating and maintenance as well as decommissioning costs associated with new build options, whether that is direct disposal or reprocessing. Standardisation will also simplify the design and operations of the future GDF.

It should be noted that the UK's fuel cycle facilities (both historic and current), have not been constructed and operated for the UK nuclear programme alone. The likes of the Thermal Oxide Reprocessing Plant (Thorp) in which the AGR fuel is reprocessed, was also used to reprocess many hundreds of tonnes of overseas fuel eg, from Europe and Japan and indeed at one time was the largest earner of Japanese Yen for the UK. This international context is an important factor when considering the UK fuel cycle facilities, not just in an historic, but also in a future context. The UK has a great deal of experience, expertise and technology that could support UK and international nuclear industry and growth – however, with the pending closure of Thorp and the Sellafield MOX Plant (SMP), continuity of expertise and knowledge could limit these opportunities.

In addition to the drive in the 1950s and 1960s for nuclear weapons material, it should also be remembered that the policy to pursue a larger nuclear energy programme and to reprocess UK spent fuel was also a strategic and economic one, driven primarily by the Suez crisis in 1956 and the oil crisis in the 1970s. With oil prices rising dramatically and a resulting shift to nuclear, the expectation was that the price of uranium ore would rise dramatically and as such, uranium had to be used more efficiently. The proposed solution was the use of fast reactors in which more plutonium is 'bred' (ie, generated) than is consumed and could, therefore, enhance the UK's energy independence. Although the concept was demonstrated technically at Dounreay in Scotland, the uranium ore price increase never materialised and the demand for a new commercial fast breeder

With the pending closure of many of the key fuel cycle facilities at Sellafield in the next few years, the UK faces issues over continuity of knowledge and expertise. If fuel cycle options are to be considered by the UK in the next few years as a nuclear programme develops, it is imperative that these skills are maintained as a minimum, even if only in an intelligent customer/custodian capacity.

reactor programme diminished. Thus in 1992 the Government announced that funding for the UK's fast reactor development programme would be terminated and in 1994 the Prototype Fast Reactor (PFR) at Dounreay was shut down.

As a consequence, until the recent public consultation (published in February 2011) and the subsequent recent Government announcement, there was no decision as to the best way to manage the plutonium separated during reprocessing. There were three major options for the Nuclear Decommissioning Authority (NDA) to consider:

- (i) continued storage
- (ii) immobilisation as a waste form
- (iii) reactor re-use

¹³² Reprocessing does create more LLW and ILW waste and in principle greater release of waste into the environment.

¹³³ Nuclear Decommissioning Authority (June 2007): 'Uranium and Plutonium: Macro-Economic Study. Final Report' – prepared by ERM and IDM <http://www.nda.gov.uk/documents/upload/Uranium-and-Plutonium-Macro-Economic-Study-June-2007.pdf>

¹³⁴ Committee on Radioactive Waste Management (July 2005): 'CoRWM's Radioactive Waste and Materials Inventory', CoRWM Document No: 1279 <http://corwm.decc.gov.uk/assets/corwm/pre-nov%202007%20doc%20archive/plenary%20papers/2006/28-30%20march%202006/1279%20-%20task%20088%20corwm%20inv%20july%202005%20final.pdf>

Unlike the plutonium, a relatively small amount of reprocessed uranium and Magnox depleted uranium has been recycled in the AGRs and Sizewell 'B'. In this sense, the UK has managed to close the fuel cycle partially. The remainder of the materials are in various states awaiting some form of disposal, as summarised above.

4.4 Future UK Fuel Cycle Options

The UK Government's policy on new nuclear build has made it very clear from the outset that the energy mix and associated technology choices should be left to the market to decide. However, when it comes to the nuclear fuel cycle options that any prospective nuclear operator may wish to consider, their options have been limited by Government policy and the content of key documents and due process eg, Justification and the Generic Design Assessment. In particular, Government has declared that reprocessing will not be considered and all of the spent fuel from new nuclear build will be directly disposed of (ie, an 'open fuel cycle') requiring it to be stored at the reactor sites, pending the availability of a future GDF.¹³⁵

Similarly, the fuel for new nuclear build will be based on uranium dioxide fuel and the requesting parties will have to explicitly exclude MOX (Mixed OXide of plutonium and uranium) fuel from any of their considerations. The exclusion of MOX from justification and GDA will result in substantial re-work for licensing and plant construction. If the Government's plutonium strategy had been clear from the outset, the requesting parties could have included MOX in their submissions and deliberations.

When it comes to the nuclear fuel cycle options that any prospective nuclear operator may have, their options have been limited by Government, which is inconsistent with the Government's energy policy of 'leave it to the markets to decide'.

Nevertheless, since the announcement in 2011 of the closure of the SMP, the UK Government's response to the consultation on management of plutonium stocks has indicated that it will pursue a preliminary policy view that re-use of plutonium as MOX fuel is the best available option to manage the UK's plutonium stocks, with any remaining plutonium that cannot be converted into MOX being immobilised and treated as waste for disposal. While the Government believes it has sufficient information to set out a direction, it is not yet sufficient to make a specific decision to proceed with procuring a new MOX plant, whereas the Royal Society's (RS) report on 'Fuel Cycle Stewardship in a Nuclear Renaissance'¹³⁶ repeats and endorses previous RS suggestions for the construction of a new MOX plant and the use of MOX in thermal light water reactors (the only proven large scale method to deal with the Pu stockpile – which can be regarded as a potential proliferation hazard). The Government is now commencing the next phase of work, which will provide the information required to take such a decision. **The key element to this decision, however, is whether the mission goal for the UK is reduction or destruction of the plutonium stocks as quickly as possible, or construction of an integrated fuel cycle and use of the plutonium as a potential valuable resource in the future, (eg, in fast reactors). These strategies are to some degree mutually exclusive. A decision by the UK is therefore required on this before the most appropriate technical choice for a reactor re-use option can be made.**

Irrespective of the reactor technology of choice for the MOX mission, it is clear that the UK's plutonium and reprocessed uranium stocks could act as a strategic asset, potentially reducing exposure to uranium price rises in the event that uranium prices escalate in the future; both reprocessed uranium and MOX involve mature technologies that could be deployed at an early stage with little technical risk. This would also be true in the future if fuel from the new build reactors was reprocessed and the material recycled.

For example, based on the current expected 60 year lifetime of a modern PWR such as AP1000 or EPR, each of these reactors will require around 1,300 tonnes of fuel, which equates to approximately 19,000 tonnes of uranium ore that would need to be

purchased. If the resulting spent fuel was reprocessed, and the plutonium and reprocessed uranium was re-used as fuel in those same reactors, approximately 25% less uranium would need to be purchased (it is a potential UK asset). At current market prices of uranium ore, this equates to a saving of more than £150m per reactor (this needs to be offset by the reprocessing costs).¹³⁷ If demand for uranium ore was to increase as new build projects started worldwide, then the uranium price would likely increase further, making the value of the recycled material even greater. The UK would need even less uranium ore if its historic plutonium and reprocessed uranium stocks were also utilised. These stocks could be used to manufacture more than 2,500 tonnes of additional new fuel, enough to fuel two additional PWRs for their entire operating lifetime.

It is important to note that the use of MOX fuel in PWRs not only places the plutonium into a strong irradiation field in the spent MOX fuel, making it much more resistant to proliferation, but it also destroys approximately one third of the plutonium loaded into the MOX fuel assemblies as well. This means that if plutonium is deemed to be a strategic asset for future fast reactors, the impact of destroying the plutonium in PWRs must also be considered as that material will form the initial fuel loads for the fast reactors. Nevertheless, since MOX is typically only loaded in one third to one half of the core in a PWR (the remainder being uranium), further plutonium is still generated in the uranium fuel which too could be reprocessed and the resulting material recycled.

Nevertheless, with the pending closure of Thorp within the next few years, any decision by the UK to change the policy on future reprocessing will mean that the UK will have to rely on overseas facilities, most likely in France, rather than an indigenous industry and/or capability. This raises important issues not only of an economic and strategic nature, but also regarding the ability of the UK to maintain the necessary skills and expertise in some of the key fuel cycle stages in the medium term. The pure economic justification for building a reprocessing plant is not great, unless there is a longer term vision BUT for countries that have such plants, it seems wasteful to close them down, until final disposal strategies are decided.

Any shift away from proven reactor technology (such as PWRs) and its associated fuel cycle – ‘proven’ in the sense that it has been demonstrated technically and economically and has also been subject to regulation and approval) – must clearly be able to demonstrate sufficiently significant benefits and overcome the ‘hurdle to change’. It is not just the operators and investors that need to be convinced, but also the regulators and other stakeholders. The main drivers for new reactors and fuel cycle options are associated typically with improved sustainability of the nuclear option through a better use of resources and better management of radioactive wastes, together with improved economics, safety and reliability, proliferation resistance and physical protection. With a modest new build programme as currently planned (around 16 GWe), the demands on uranium ore and fuel cycle facilities (primarily the interim spent fuel storage ponds and ultimately the GDF) are relatively limited. However, if new nuclear build expands in the UK to the levels proposed by some commentators (of the order of 40–80 GWe) then a similar expansion could be envisaged elsewhere in the world, with a resulting demand and thus price increase for the uranium ore. It is clear that under these circumstances, alternative fuel cycles, particularly those associated with better uranium utilisation, will be key, with the role of fast reactors and closing the fuel cycle ie, reprocessing and recycle being major factors. As part of these future developments, the proliferation concerns raised over the separation of pure plutonium are being addressed in advanced reprocessing techniques, where the plutonium is co-separated with uranium and/or other minor actinides such as neptunium, thus increasing the proliferation resistance of the separated material.

For fast reactors (some of the Generation IV designs), the intention is to reach a situation where the programme produces just enough plutonium to replace what it consumes ie, it is self sustaining. This allows the potential exploitation of the full energy content of uranium, both fissile and fertile isotopes (ie, those isotopes that do not undergo fission themselves, but on capturing a neutron are transformed into fissile material), and also of all actinides found in the waste through their recycling. The way this is achieved is to ‘breed’ plutonium by using uranium tails ie, the residue from the historic enrichment process. There is a sufficient stock of existing uranium tails in the UK (currently stored as ‘residues’) to fuel a new build fleet of several tens of GWe of fast reactors for their entire design lifetime, ie, the UK already has sufficient fuel stocks for future fast reactors without having to buy any more uranium ore or for any further mining to take place. However, a ‘driver’ fuel which produces the neutrons to allow the breeding to take place is required and this is where the UK’s historic plutonium stocks could be used.

Although there is a lot of potential in the fast reactor technologies and associated fuel cycles, they are yet to be demonstrated on a commercial or large scale. There are extensive international research programmes already underway looking to address the remaining issues, but the commercial deployment in the UK is still likely to be some 30 to 40 years away. It should be noted that there are accelerated fast reactor programmes in China and India, and the UK may benefit from the demonstration of the technology in these programmes. Nevertheless, with PWR lifetimes of approximately 60 years, a transition to the new technologies in the UK can be foreseen as confidence is gained in the new technology and the world-wide growth of nuclear places further demand on the uranium resource.

An alternative option to using the existing stocks of uranium tails is to use thorium. Naturally occurring thorium consists entirely of ^{232}Th , which is a fertile nuclide ie, it does not undergo fission itself, but on capturing a neutron it is transformed to fissile ^{233}U . In the same way as in natural uranium, ^{238}U is a fertile nuclide which transforms to fissile ^{239}Pu . However, because thorium does not have a naturally occurring fissile isotope (unlike natural uranium which contains a small percentage of ^{235}U), the thorium fuel cycle needs another fissile material, either ^{235}U or ^{239}Pu , to get started. In its simplest form of implementation, with a once-through fuel cycle, thorium fuel can be used to augment the useful energy output produced per tonne of uranium ore, but this benefit is relatively small. However, with the reprocessing of thorium fuel and recycle of the ^{233}U , it is theoretically possible to achieve a breeding cycle in a thermal reactor. With the uranium-plutonium fuel cycle a thermal reactor breeder cycle is difficult to achieve. As with the uranium-plutonium fuel cycle, the main advantage of the breeding cycle is only realised once a fully closed fuel cycle is achieved ie, reprocessing and recycle is required. The disadvantage with the thorium fuel cycle is that the fuel technology and moreover the reprocessing technology is not proven on a commercial scale and is notably more difficult owing to the chemical processes involved. Furthermore, many of the concepts for thorium fuels require new reactor technologies as well as unproven fuel cycle technologies. These technologies have very little active research underway currently and so there are extended timescales before this option could be realised and this also carries notable risk.

Although more abundant than uranium in the earth’s crust, the deposits are not necessarily as concentrated as uranium and indeed there is currently no major commercial mining or refining of thorium in those countries where

¹³⁵ Department of Energy and Climate Change (October 2010): ‘The Justification of Practices Involving Ionising Radiation Regulations 2004’ DECC: London <http://www.decc.gov.uk/assets/decc/What%20we%20do/UK%20energy%20supply/Energy%20mix/Nuclear/newnuclear/667-decision-ap1000-nuclear-reactor.pdf>

¹³⁶ Royal Society Science Policy Centre report (2011): ‘Fuel cycle stewardship in a nuclear renaissance’ Royal Society: London <http://royalsociety.org/policy/projects/nuclear-non-proliferation/report/>

¹³⁷ Reprocessed uranium is not suitable for LWRs unless it is re-enriched and this will require an enrichment plant capable of dealing with slightly radioactive material. The French are building one such line at the Georges Besse II plant.

it is in abundance. India is the major exception, with a strong commitment to the thorium fuel cycle because of its large indigenous reserves of thorium, the very ambitious nuclear expansion planned and an acute shortage of access to uranium ore. Also, until recently, India was prevented from accessing international nuclear technology, including uranium ore and fuel supply, due to proliferation concerns, and was forced to develop its own technology.

The technology is innovative, although technically immature and currently not of interest to the utilities, representing significant financial investment and risk without notable benefits. In many cases, the benefits of the thorium fuel cycle are often over-stated and as yet unproven. In particular, the non-proliferation claims of the thorium fuel cycle are overstated as the IAEA, under the Convention on the Physical Protection of Nuclear Materials, categorises ^{233}U on the same basis as plutonium (^{239}Pu).

4.5 Conclusions

Over time, the historic UK fuel cycle choices have been made for a variety of reasons, whether they be military, commercial or technical. Nevertheless, the drivers are varied and are often temporal. Therefore, the future choices for the UK must be considered from a wide range of perspectives and by the appropriate stakeholders; they must consider all of the appropriate drivers eg, sustainability, economics, safety, reliability, proliferation resistance, physical protection etc. However, amongst the stakeholders, drivers are often viewed in inconsistent ways and certainly with different priorities. With this in mind and considering the current UK Government view that 'the markets will decide', the question remains of who will make the decisions over the future UK fuel cycle options. The current and future nuclear utilities will have economics along with safety as their highest priority. In contrast, Government bodies such as the NDA have 'value for the UK tax payer' as their main priority while the public at large are mainly concerned with the safety, economics and waste issues associated with nuclear. So who

is addressing the future sustainability of nuclear as a low carbon technology, uranium ore utilisation and, overall, the nuclear fuel cycle issues? This decision should sit with the UK Government, but with flexibility, given the changing world circumstances, so that the operators can determine what are their most suitable options, including the potential to recycle and use MOX fuel.

A clear, consistent and long term strategy will be key to the success of the nuclear fuel cycle of the future as well as to the sustainability issues in the successful application of nuclear energy generation and its impact on future generations eg, managing the wastes, efficient use of uranium ore and effective use of the GDF. Because of inconsistencies over the years in policy and technology, the UK finds itself with a variety of materials, waste products and spent fuel, each with different processing and handling needs, which has resulted in a significant number of facilities together with the associated challenges not just with the operations, but also the subsequent decommissioning of the legacy sites. A move to PWRs (and potentially fast reactors in the future) and an integrated, consistent fuel cycle in the future will dramatically reduce the number of diverse facilities required and thereby the operating and maintenance as well as decommissioning costs associated with new build options, whether direct disposal or reprocessing is ultimately chosen.¹³⁸

In the absence of an organisation like the historic British Nuclear Fuels Ltd (BNFL), there is no organisation responsible for considering and addressing the UK's integral fuel cycle issues of the future. BNFL used to fund and manage the UK's participation in international research and development programmes on advanced reactors and fuel cycles, eg, the UK's participation in the Generation IV International Forum and associated technical programmes. With the absence of UK participation in these programmes along with lack of investment in future fuel cycle options for the UK, there is a clear danger of the UK losing the necessary

skills to adopt and adapt the appropriate fuel cycle technologies of the future, whether this is a commercial opportunity for UK industry or simply as an 'intelligent customer' of the future. Certainly the continuity of knowledge of lessons to be learnt from historic choices and technology developments will remain a major concern.

The fuel cycle choices for the UK will be heavily dependent on the size of the role of nuclear in the future. As a minimum, the varied legacy spent fuels and wastes will have to be managed along with the spent fuel arising from new build. Management of historic plutonium stocks, most likely in the form of MOX fuel, irradiated in the new build PWRs such as AP1000 or EPR, will also be required. However, if nuclear is to play a more considerable role in the energy production for the UK, and if the possible nuclear renaissance is seen world-wide, then demands on uranium ore are inevitable. These demands will naturally result in new prospecting for uranium ore, but they will more likely still result in an increase in the price of uranium and this will lead to a need for increased consideration of uranium ore utilisation. Such improvements will most likely occur via reprocessing, recycling and the future use of fast reactors. Use of the UK's legacy uranium tails becomes a real win-win for the UK at that time in the sense that there are sufficient existing uranium tails in the UK (currently stored as 'residues') to fuel a new build fleet of several tens of GWe of fast reactors for their entire design lifetime ie, the UK already has sufficient fuel stocks for a significant future programme of fast reactors without having to buy any more uranium ore.

Any decision to proceed with a reactor technology and a given fuel cycle has implications not just during the planning and operations phases of a new build programme today but for decades and centuries ahead and indeed the timing of the new build programme and the degree of farsightedness of the nation will also govern which option(s) are selected. In order to maintain these future options it is essential that the UK maintains and grows an R&D programme associated with the nuclear fuel cycle.

¹³⁸ An alternative future approach, if there is a tendency post Fukushima to move away from light water reactors, would be to develop high temperature reactors.



The future nuclear technologies

Ever since the start of the civil nuclear age, research has been undertaken to address the limitations of LWR technology, especially the low thermodynamic efficiency and the need to operate in a thermal spectrum, which essentially limits the exploitation of uranium to just the fissile ^{235}U fraction.

5.1 Background

Since the 1960s, numerous demonstrator and prototype reactors have been constructed and operated that use different fuel designs, coolants and degrees of moderation. In particular, reactors with less moderation, so-called fast neutron reactors (FNRs), have been built in several countries and are capable, through the ability to breed efficiently fissile ^{239}Pu from fertile ^{238}U , of producing at least 50 times more energy from the same quantity of natural uranium than LWRs. Though never developed to the level of wide-scale commercial exploitation, these prototype FNRs have certainly demonstrated the feasibility of vastly enhanced uranium resource sustainability. They include notably Phénix and Superphénix in France, the former operating at Marcoule from the early 1970s to the end of 2009 and the latter closed in 1997; the Experimental Breeder Reactor I and II in the U.S.; the UK's FNR programme which came to an end with the closure of the PFR (Prototype Fast Reactor) at Dounreay in 1994 after 20 years of operation. Currently, FNRs are in operation in Russia and Japan, under construction in Russia, India and China, and planned in a number of countries, including ASTRID¹³⁹ (Advanced Sodium Technical Reactor for Industrial Demonstration) in France. The Chinese fast reactor was connected to the grid on 21 July 2011.

These projects have been largely carried out as part of national R&D programmes with limited investment from industry. On the other hand, industry has been very active in refining LWR technology driven by normal commercial competition as well as regulatory requirements, and this has resulted in the evolutionary Generation III designs available today. It is clear that there is little incentive for industry to invest heavily in developing radically new designs in view of the long term uncertainty, be it political, financial or regulatory. This reticence is even more understandable in view of the current liberalisation of the electricity markets. Revolutionary advances in technology in these circumstances will only come about with appropriate support at national level.

5.2 The Future – Drivers for Change

A number of areas can be identified that will drive the development of future systems. These include continuing concerns regarding safety and non-proliferation, economic performance, a growing market for large-scale production of low-carbon heat for industrial processes, the need to optimise the use of future geological repositories, and in particular sustainability of natural uranium reserves. In view of the widespread agreement on the importance of these drivers, many countries share a common interest in undertaking the

necessary R&D, and it therefore makes sense for nations to collaborate in order to aid progress toward the realisation of such systems, leverage resources, provide synergistic opportunities and avoid unnecessary duplication.

Regarding uranium resources in particular, the picture over the long term is far from clear. Though the NEA's biennial Red Book,¹⁴⁰ the recognised authority on the subject, currently considers resources plentiful and known reserves increasing, this is no reason to waste them – and this assumes new mines go ahead. There is considerable uncertainty regarding future new-build growth rates and even the possibilities of opening major new uranium mining exploitations. Utilities faced with decisions on new build around the middle of the century will need assurances that uranium supply will remain relatively cheap and plentiful for the expected lifetime of the their plant, which in the case of Gen-III technology with lifetime extension could be as much as 80 years. Failure to reassure potential customers on this crucial issue will tip the balance in favour of alternatives, and it is then that Gen-IV FNR models would need to be commercially available.

¹³⁹ <http://www.world-nuclear-news.org/newsarticle.aspx?id=28382> and http://www.cea.fr/le_cea/actualites/accord_collaboration_areva_cea_astrid-42715

¹⁴⁰ Nuclear Energy Agency (NEA), Organisation for Economic Co-operation and Development (OECD), The Joint NEA/IAEA Group on Uranium (UG) <http://www.oecd-neo.org/ndd/uranium/>

5.3 Gen-IV – a Revolution in Nuclear Design

In 2000, at the instigation of the US Department of Energy (DoE), experts from around the world began formulating the requirements for the next generation of nuclear systems that could respond to the world's future energy needs, in particular in a scenario of increased demand, especially for electricity, and reduced CO₂ emissions. Increased sustainability of uranium natural resources and minimising waste production become major concerns in such a scenario, in addition to satisfying economic competitiveness and maintaining stringent standards of safety and proliferation resistance. The emergence of new applications, such as hydrogen production or water desalination, is expected to offer other uses for Gen-IV technology.

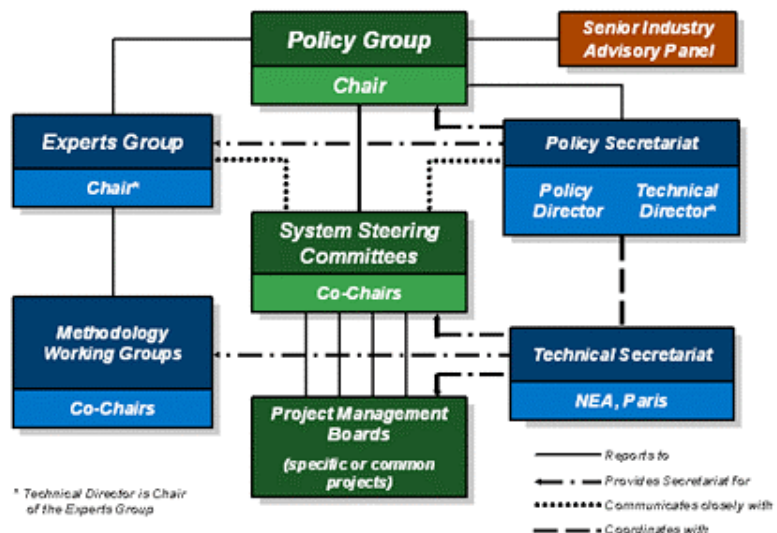
The initiative led to the establishment of the Generation-IV International Forum¹⁴¹ (GIF), which brings together the major civil nuclear power programme nations in a collaborative venture focused on pre-conceptual design (ie, essentially pre-commercial) research in advanced nuclear technology.

The GIF governance comprises a high-level Policy Group with representatives of all the active members advised on technical issues by the Expert Group. Three Methodology Working Groups – Proliferation Resistance and Physical Protection, Economic Modelling and Risk and Safety – provide the methodological framework in each of the major cross-cutting areas. In addition, the Policy Group has established a Senior Industry Advisory Panel of high-level representatives from the nuclear industry, both vendors and utilities, in order to ensure the views of industry are heard. The OECD / NEA provides the GIF technical secretariat, managing in particular the interaction within the various systems and projects, the flow of information and control over access to intellectual property and generated information. It is also the depository for the legally binding agreements signed between the parties. The NEA's technical services are funded by cash or in-kind contributions from the GIF members.

Figure 3: The Generation-IV International Forum today

	Argentina		Republic of Korea	<p>All GIF members are signatories to the GIF Charter [i]. Ten members have since acceded to the Framework Agreement (FA) [ii], which is a binding agreement between nations, and establishes system [iii] and project [iv] organisational levels for further cooperation. Non-active members are those among the nine founding members in 2001 that have not yet acceded to the FA – this includes the UK. Non-founding members joining the GIF are committed to acceding to the FA within 12 months of signing the Charter. The most recent non-founding members include China and Russia, both of whom have now acceded to the FA. Accession to the FA requires the member to nominate an Implementing Agent (eg, in the case of France this is the CEA, in the case of Euratom it is the European Commission Joint Research Centre – JRC).</p> <p>UK situation: The UK was one of the founding members, signing the Charter in 2001, but following a reversal of policy never ratified the FA and became non-active. It no longer takes part in any of the activities in its own right nor is it represented in the GIF governance bodies. However, thanks to the participation of Euratom, UK organisations can still cooperate in the GIF, albeit at reduced levels compared with possibilities offered via national involvement.</p> <p>[i] http://www.gen-4.org/PDFs/GIFcharter.pdf [ii] http://www.gen-4.org/GIF/Governance/framework.htm [iii] http://www.gen-4.org/Technology/systems/index.htm [iv] http://www.gen-4.org/GIF/Governance/project.htm</p>
	Brazil*		Russian Federation	
	Canada		South Africa	
	People's Republic of China		Switzerland	
	Euratom		UK*	
	France		USA	
	Japan	*non-active member		

Figure 4: GIF Governance Structure



¹⁴¹ Generation-IV International Forum (GIF) <http://www.gen-4.org/>

It should be stressed that the concept of Gen-IV technology lies in the defining criteria and not a particular type of reactor. These criteria, as established at an early stage by the GIF, are outlined below.

Sustainability:

- Gen-IV nuclear energy systems will provide sustainable energy generation that meets clean air objectives and provides long-term availability of systems and effective fuel utilisation for worldwide energy production.
- Gen-IV nuclear energy systems will minimise and manage their nuclear waste and notably reduce the long-term stewardship burden, thereby improving protection for the public health and the environment.

Economics:

- Gen-IV nuclear energy systems will have a clear life-cycle cost advantage over other energy sources.
- Gen-IV nuclear energy systems will have a level of financial risk comparable to other energy projects.

Safety and Reliability:

- Gen-IV nuclear energy systems operations will excel in safety and reliability.
- Gen-IV nuclear systems will have a very low likelihood and degree of reactor core damage.
- Gen-IV nuclear energy systems will reduce the need for offsite emergency response.

Proliferation Resistance and

Physical Protection:

- Gen-IV nuclear energy systems will increase the assurance that they are very unattractive and the least desirable route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts of terrorism.

The Gen-IV process is therefore an opportunity to return to basic principles in the development process, allowing safety to be designed into the plant at a very early stage rather than being added on later. This resulting increased emphasis on passive and inherent safety (eg, use of gravity, natural circulation, etc.) will be a hallmark of Gen-IV systems, and is particularly important in the aftermath of Fukushima, which demonstrated the weakness in extreme scenarios of certain active safety measures.

5.4 Advanced Designs

In the very early days of the GIF, some 100 experts from around the world examined a range of possible reactor designs and associated fuel cycles in order to assess their suitability in the context of future energy needs. This led to a down-selection to just six basic concepts (Figure 5) that would be the initial focus of attention within the GIF. However, it will take at least two or three decades before the deployment of commercial Gen-IV systems. Furthermore, the Gen-IV concepts currently under investigation are not all on the same timeline and some might not even reach the stage of commercial exploitation. Some of the concepts under study have already been operated in the past using the technology available at that time, though considerable R&D is needed to turn these into technology worthy of the Gen-IV label.

In each of the six GIF systems, the required research effort is governed by a detailed System Research Plan (SRP) agreed and maintained by the experts in the respective System Steering Committee. In four of the systems, formal binding Systems Arrangements (SAs), signed between GIF Implementing Agents, are in force and a number of common R&D projects have been launched, with well-defined deliverables, milestones and time schedule, and within a clearly defined contractual framework (the Project Arrangement

– PA), which also includes provisions for IPR and the license-free exchange of generated information for research purposes. The GIF does not fund research directly; instead all contributions are made in kind by the members and the results offered within the framework of the SAs and PAs. The Policy Group monitors the value of this combined research effort in the various systems.

The four SAs currently in force are for the SFR, VHTR, SCWR and GFR. Only Canada and Switzerland are not parties to the SFR SA, and only Russia is not involved in the VHTR. In view of the broad research base across the EU member states, Euratom is a party to all four SAs, partnering with Japan and Canada in the case of the SCWR and with France, Japan and Switzerland in the case of the GFR. Under these four SAs, some ten PAs are also now signed and in force – four for the SFR, three for the VHTR, and two and one for the SCWR and GFR respectively. This involvement in SAs and distribution of PAs is probably indicative of the general interest worldwide in the various systems, with the SFR and the VHTR being the most popular (these are also the systems in which there is the most previous experience). Euratom is actively involved in seven of the ten PAs, but in only one of the four under the SFR. This is probably explained by the fact that the majority of European competence in the SFR is retained within France, which participates in the GIF in its own right.

Figure 5: Overview of Gen-IV Systems

System	Neutron spectrum	Coolant and outlet temp. °C	Fuel cycle	Size (range MWe)
VHTR (Very High Temperature Reactor)	thermal	helium, 900–1000	open	250–300
SFR (Sodium-cooled Fast Reactor)	fast	sodium, 550	closed	30–150 300–1500 1000–2000
SCWR (Supercritical Water-cooled Reactor)	thermal/fast	water, 510–625	open/ closed	300–700 1000–1500
GFR (Gas-cooled Fast Reactor)	fast	helium, 850	closed	1200
LFR (Lead-cooled Fast Reactor)	fast	lead, 480–800	closed	20–180 300–1200 600–1000
MSR (Molten Salt Reactor)	epithermal	fluoride salts, 700–800	closed	1000

The **Very High Temperature Reactor** is a next step in the evolutionary development of high-temperature gas-cooled reactors, which have operated in the past (including the AVR in Germany and the Dragon at Winfrith in the UK in the 1960s and 70s), and for which demonstrator plants are currently in operation or under construction in Japan and China. Others, such as the NNGP – Next Generation Nuclear Plant – in the USA are planned and would push the technology further towards Gen-IV goals. The VHTR reference thermal power is set at a level that allows passive decay heat removal, currently estimated to be about 600 MWth. The VHTR is primarily dedicated to the cogeneration of electricity and hydrogen, as well as producing low carbon process heat for other industrial applications. Hydrogen can be produced using thermo-chemical, electro-chemical or hybrid processes with reduced emission of CO₂. Initially, a once-through low-enriched uranium (<20% ²³⁵U) fuel cycle will be adopted, but a closed fuel cycle will also be assessed, as well as potential symbiotic fuel cycles with other types of reactors (especially LWRs) for waste reduction.

In view of the UK's considerable experience in gas-cooled graphite-moderated reactor technology, this is one reactor concept in which significant UK R&D involvement could be expected. Thanks to past and current Euratom projects, Euratom is contributing significantly to GIF collaborations in all the PAs within the VHTR system, and UK partners are present in these Euratom projects (those most involved include the University of Manchester, Alstom Power Ltd and AMEC).

The **Sodium-cooled Fast Reactor** couples high power density with low coolant volume fraction. The reactor can be arranged in a pool layout or a compact loop layout. A variety of different reactor size options are currently under consideration, from small (50 to 300 MWe) modular reactors to considerably larger versions (up to 1500 MWe). The two primary fuel recycle technology options are advanced aqueous and electrometallurgical processing (pyroprocessing). A variety of fuel options are being considered, with mixed oxide preferred for advanced aqueous recycle and mixed metal alloy preferred for pyrometallurgical processing. Owing to the significant past experience accumulated with sodium-cooled reactors in several countries, demonstrator Gen-IV SFR systems could be in operation within the next decade.

The SFR is the reference technology in the European Sustainable Nuclear Industrial Initiative (ESNII),¹⁴² one of seven European Industrial Initiatives (EIs) under the SET-Plan¹⁴³ (Strategic Energy Technology Plan), the EU's principal 'technology push' initiative as part of the drive to establish a European low carbon economy by 2050. Other SET-Plan EIs focus on renewables (wind, solar and bio-energy), CCS, electricity grids and smart cities.¹⁴⁴ ESNII is an umbrella initiative for a number of Gen-IV FNR demonstrator projects, bringing together 13 key European nuclear research and industrial players including AMEC and NNL. Apart from the SFR, for which the French ASTRID project is the demonstrator, ESNII includes plans for demonstrators for two alternative concepts – the GFR and LFR (see below). However, the UK national SFR programme ended many years ago, and it

is unlikely that much expertise still remains in the area of reactor design or SFR operations, although it is recognised that fuel development, fuel and core design and performance, materials and fuel cycle activities are still relatively strong. Furthermore, the Euratom contribution to GIF in the SFR system is relatively modest since the French contribute directly. However, the Civil Nuclear Cooperation Agreement¹⁴⁵ signed recently between UK and France also strengthens ties in the area of research in Gen-IV systems, which may open the door for increased involvement of the UK in ASTRID in those areas where appropriate UK competences still exist.

The **Supercritical Water Reactor** is a high-temperature, high-pressure water-cooled reactor operating with a direct energy conversion cycle and above the thermodynamic critical point of water (374°C, 22.1 MPa). The higher thermodynamic efficiency and plant simplification opportunities afforded by a high-temperature, single-phase coolant translate into improved economics. A wide variety of options are currently being considered, and both thermal neutron and fast neutron spectra are envisaged and pressure vessel or pressure tube configurations are considered. The SCWR would enable synergies with fossil fuel thermal power plants already operating with supercritical water as coolant, and would enable many aspects of current LWR technology to be further developed.

Euratom is one of the main exponents of research in this Gen-IV concept within the GIF, with organisations in the Czech Republic and Germany being the most active. However, there is currently no interest from UK-based organisations.

¹⁴² European Sustainable Nuclear Industrial Initiative (ESNII) <http://www.snetp.eu/> – menu: 'Activities', option 'ESNII'

¹⁴³ The European Strategic Energy Technology Plan (The SET-Plan) http://ec.europa.eu/energy/technology/set_plan/set_plan_en.htm and Strategic Energy Technologies Information System (SETIS) <http://setis.ec.europa.eu/about-setis/overview>

¹⁴⁴ Strategic Energy Technologies Information System (SETIS) – Industrial Initiatives <http://setis.ec.europa.eu/activities/initiatives>

¹⁴⁵ No. 10 (Official site of the British Prime Minister's Office)(17 February 2012): 'UK France Declaration on Energy' <http://www.number10.gov.uk/news/declaration-on-energy/>

The main characteristics of the **Gas-cooled Fast Reactor** are fissile self-sufficient cores with fast neutron spectrum, robust refractory fuel, high operating temperature, high efficiency electricity production, energy conversion with a gas turbine and full actinide recycling possibly associated with an integrated on-site fuel reprocessing facility. No fast reactor cooled by gas has ever been constructed or operated, and if this concept is to be developed past the design and basic R&D stage, a low power technology demonstration reactor would first be needed to qualify key technologies.

Along with the LFR, this is one of the two alternative FNR technologies under consideration in ESNII. Although still at a very early phase, there have been moves at national level in the Czech Republic, Slovakia and Hungary to collaborate in the siting of a GFR demonstrator plant (the French inspired ALLEGRO project) in one of these countries, possibly with the help of EU Structural Funds. Once again, UK experience in gas-cooled technology would imply significant interest from UK-based research partners. Indeed, the Euratom project GOFSTR (3-year duration ending Feb. 2013, 22 consortium partners, total budget = €5.4M) dealing with aspects of the GFR design as part of GIF collaborations is coordinated by AMEC and also includes Imperial College and NNL from the UK. However, France remains the principal driver for this research in Europe, and there is uncertainty at the moment how much this concept will feature in French strategy in the future.

The **Lead-cooled Fast Reactor** would offer the possibility of a closed fuel cycle with full actinide recycling, possibly in central or regional fuel cycle facilities. The coolant could be either lead or lead/bismuth eutectic. The LFR can be operated as a breeder,

a burner of actinides from spent fuel using inert matrix fuel, or a burner/breeder using thorium matrices. Two reactor size options are being considered: a small transportable system of 50 to 150 MWe with a very long core life and a medium system of 300 to 600 MWe. In the long term a large system of up to 1200 MWe could be envisaged. The country with the most experience with lead-cooled reactor technology is undoubtedly Russia, with LFR systems being used in the past as power sources in nuclear submarines. Based on this technology, Russia has plans to develop a commercial plant using lead/bismuth eutectic within the next 10 years. Nonetheless, within the GIF there has been to date no interest in establishing a formal legally binding System Arrangement and subsidiary Project Arrangements for the LFR. However, some of the research is closely related to that being undertaken for the SFR, and a Memorandum of Understanding (MoU) between Euratom, Japan and Russia has recently been signed in order to pursue GIF collaborations in a less formal framework.

In Europe there is widespread interest in lead-cooled systems as a result of considerable investment in research on P&T (partitioning and transmutation) and related Accelerator Driven Systems (ADS) in recent years, much of it supported through Euratom. The ADS is seen as an efficient transmutation system for burning long-lived waste, and has therefore continued to be supported even by countries with an ambivalent attitude towards advanced nuclear power technology. The €1bn MYRRHA project¹⁴⁶ in Belgium is the culmination of this effort, and has already being given the initial go-ahead and funding from the Belgian Government. Initially this will be an ADS coupling a high powered proton accelerator to a lead-bismuth eutectic cooled core, but in the longer term the intention is to operate

it in critical mode (ie, without accelerator) as an energy technology pilot plant for the LFR system under the ESNII umbrella. A European LFR demonstrator project (ALFRED) is also under consideration by ESNII, and as for ALLEGRO the idea is that it would be hosted by a new EU Member State and benefit from support via EU structural funds. There is no past experience in LFR technology in the UK and little interest amongst UK research stakeholders in heavy liquid metal (HLM) systems in general, including ADS; practically no UK partners are involved in the numerous Euratom projects linked with MYRRHA.

The **Molten-Salt Reactor** embodies the very special feature of a liquid fuel. MSR concepts, which can be used as efficient burners of minor actinides from spent LWR fuel, have also a breeding capability in any kind of neutron spectrum ranging from thermal (with a thorium-based fuel cycle) to fast (with the U-Pu fuel cycle). Whether configured for burning or breeding, MSRs have considerable promise for the minimisation of radiotoxic nuclear waste. Some past experience of this concept was gained in the USA in the 1960s and 70s, and there is still some interest today in parts of Europe and also in Russia. As with the LFR, so far there has been no interest amongst GIF members to progress towards legal instruments to govern the collaborative research on the MSR, and instead an MoU, presently agreed only between Euratom and France, is the current basis for GIF collaborations.

Perhaps the principal organisation interested in this concept in Europe is the French CNRS (Centre national de la recherche scientifique), which is currently the coordinator of a relatively small Euratom project, EVOL, carried out in collaboration with Russia (Rosatom). Regarding UK interest, Oxford University is one of the eleven partners in the EVOL consortium.

¹⁴⁶ SCK•CEN: Multi-purpose hybrid research reactor for high-tech applications (MYRRHA) <http://myrrha.sckcen.be>

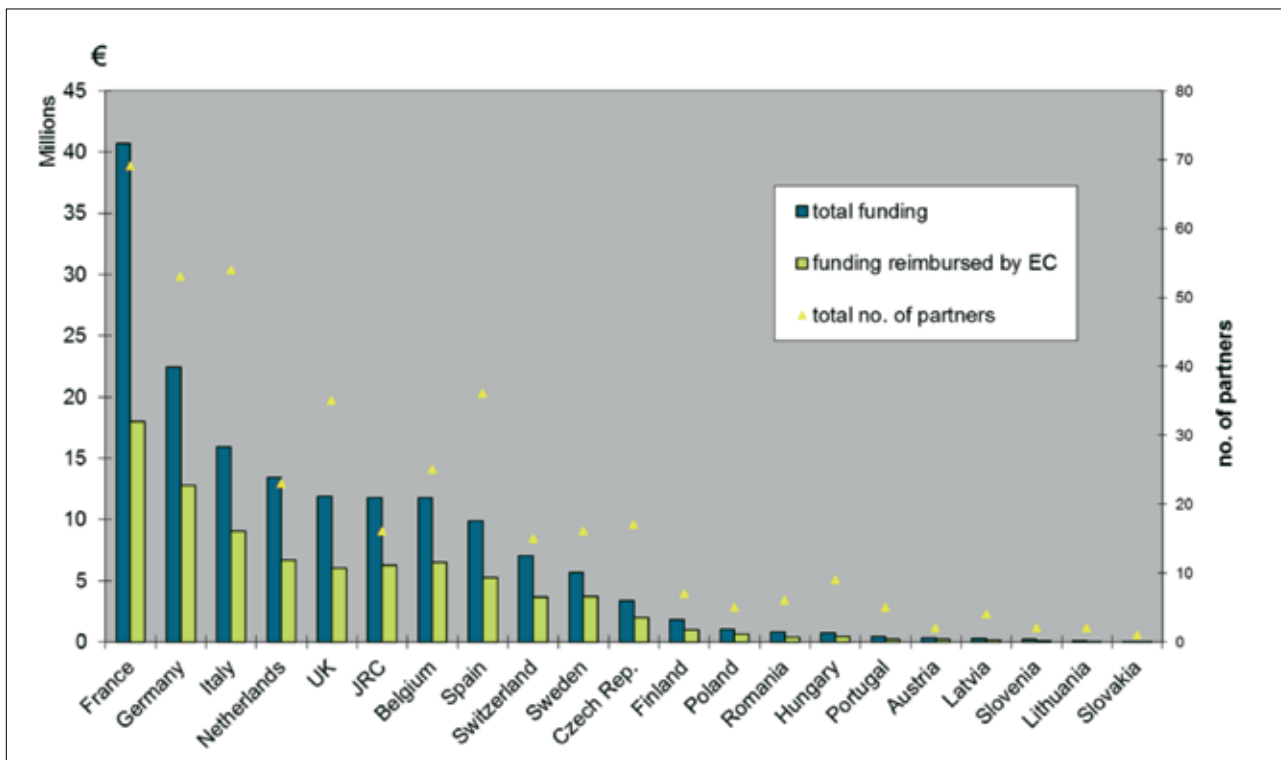
5.5 The UK's Contribution to Gen-IV Research through Euratom

Though UK organisations can continue to participate in international cooperation in Gen-IV research through Euratom membership in GIF, this involvement is necessarily constrained by Euratom policy and the level of funding available through the Euratom Framework Programme (the principal instrument to support nuclear research at the EU level). In recent years, the annual Euratom budget for support to research carried out in member states in all areas of nuclear fission and radiation protection has been very modest, c. €50m, and only a fraction of this is devoted to research on advanced concepts. Furthermore, as a result of the need for unanimous support by EU member states in Council on the adoption of Euratom Framework Programmes, it is unlikely that this level of funding will rise significantly in the future, certainly as regards research in the area of Gen-IV. The question therefore arises whether the UK's interests can be adequately served by Euratom alone.

Nonetheless, an idea of the recent interest and capabilities in the UK regarding Gen-IV research can be gained from statistics on involvement in relevant Euratom projects. Figure 6 shows the breakdown of funding in projects on Gen-IV launched within the Euratom Seventh Framework Programme (2007–2011) following open calls for proposals. Projects are carried out by multi-partner consortia usually on the basis of shared cost, with approximately 50% provided by Euratom and the remainder by the partners themselves, though SMEs and educational establishments are reimbursed by Euratom at 75%. A wide range of projects have been launched over the duration of Euratom FP7 on topics related to Gen-IV, either focused on GIF systems as part of the Euratom contribution to GIF (in which case the projects are usually defined with the help of the Euratom representatives in the relevant GIF System Steering Committees), or in cross-cutting fields such as nuclear safety, materials, fuel cycle (reprocessing and recycling), nuclear data, thermal hydraulics, etc.

In total, some 22 projects, amounting to a Euratom contribution of c. €80m (total funding c. €160m), can be identified, and UK-based partners are present in most of these, often more than one per project, and benefit from some €6m of Euratom funding. However, this represents only fifth place in the funding table, behind France, Germany, Italy and the Netherlands, and on a par with Belgium and the European Commission's own JRC, which can also benefit from these open calls for proposals. Interestingly, of the 16 UK-based organisations involved, half are universities receiving funding ranging from as low as €8,000 to about €300,000. AMEC is present in five projects, notably those focused on specific Gen-IV systems such as CP-ESFR (SFR), ARCHER (VHTR) and GOFASTR (GFR). In the latter case AMEC is also the project coordinator, the only UK organisation to play this key role in these Gen-IV-related projects. NNL is present in four projects, but plays significant roles in only two fuel-cycle-related projects dealing with advanced partitioning, recycling and reprocessing (ACSEPT and ASGARD). The most active universities are Manchester followed by

Figure 6: Breakdown of Funding in Gen-IV Projects Launched within the Euratom Seventh Framework Programme (2007–2011)



Imperial College, and in the case of all university participation there is a preference for more fundamental research in areas such as materials. Judging by the number of UK-based partners involved and the level of funding, the most popular topics with UK organisations appear to be gas-cooled technology (VHTR or GFR) or those dealing with the fuel cycle. Apart from AMEC, there appears to be little interest in SFR topics, though the Euratom programme itself has a limited number of projects focused specifically on SFR technology.

Not all the above Euratom projects are likely to produce results of interest within GIF. However, in those cases where new generated data can contribute to the milestones in the GIF systems roadmaps, Euratom will offer them to GIF in agreement with the consortium partners in the Euratom project. This potentially will lead to reciprocal access to data from other GIF members contributed within the same PA. Detailed information on access to and exchange of such information within the GIF is currently lacking, but it is expected that as projects get up to speed in the various GIF members more such contributions will be made, and this will become an effective means of cooperation amongst the countries and research organisations involved. However, it is probably true to say that progress to date in this regard has not been rapid, the GIF having been bogged down for many years on resolving legal issues and agreeing the terms of the SAs and PAs, in particular regarding IPR and exchange of information.

5.6 Other International Forums

GIF is the only international forum in the field of advanced fission systems with the aim of fostering collaboration in R&D and with a contractual framework to promote these efforts. Nonetheless, other initiatives are also on-going, under the auspices of either the IAEA or NEA or, in the broader international context, that are contributing in the area of strategy / policy or on related regulatory issues. The principal ones are described in more detail below. In addition, there are other collaborative initiatives coordinated either by the NEA or IAEA as part of their routine activities in the nuclear field (eg, the IAEA CRPs – Coordinated Research Programmes – or working parties and ad hoc expert groups set up under the NEA's Nuclear Development Committee, amongst others) that involve representatives of UK-based organisations and may also cover issues related to advanced systems.

The Multinational Design Evaluation Programme¹⁴⁷ (MDEP) is a multinational initiative taken by national safety authorities, including the UK's ONR, to develop innovative approaches to leverage the resources and knowledge of those national regulatory authorities currently responsible for, or who may in the future need to undertake, the review of new reactor power plant designs. As with the GIF, the NEA serves as the technical secretariat. The MDEP programme incorporates a broad range of activities including enhanced multilateral cooperation within existing regulatory frameworks, multinational convergence of codes, standards and safety goals, and implementation of MDEP products to facilitate the licensing of new reactors, including those being developed

by the Generation IV International Forum. A key concept throughout the work of MDEP is that national regulators retain sovereign authority for all licensing and regulatory decisions.

The International Project on Innovative Nuclear Reactors and Fuel Cycles¹⁴⁸ (INPRO) was established by the IAEA in 2000 to help ensure that nuclear energy is available to contribute to meeting the energy needs of the twenty-first century in a sustainable manner. It is a mechanism for IAEA member states to collaborate on topics of joint interest. Currently 35 IAEA member states collaborate within INPRO, including all the active GIF members, and in addition the European Commission is represented. The UK is not a member, though INPRO's output is shared with all IAEA members. INPRO is essentially a policy forum and its role is not to carry out collaborative R&D activities on advanced technology. There are regular interface meetings between GIF and IAEA/INPRO Managers.

The International Framework for Nuclear Energy Cooperation¹⁴⁹ (IFNEC), which grew out of the ill-fated Global Nuclear Energy Partnership (a President Bush initiative launched in 2006), has the mission 'to provide a forum for cooperation among participating states to explore mutually beneficial approaches to ensure the use of nuclear energy for peaceful purposes proceeds in a manner that is efficient and meets the highest standards of safety, security and non-proliferation ... participating states would not give up any rights and voluntarily engage to share the effort and gain the benefits of economical, peaceful nuclear energy'. The UK is an IFNEC member. IFNEC is much more concerned with issues such as fuel services and infrastructure, though where there are links with advanced technology these will probably be coordinated with INPRO.

¹⁴⁷ Nuclear Energy Agency (NEA) – Multinational Design Evaluation Programme (MDEP) <http://www.oecd-nea.org/mdep/>

¹⁴⁸ International Atomic Energy Agency (IAEA) – International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) <http://www.iaea.org/INPRO/>

¹⁴⁹ International Framework for Nuclear Energy Cooperation (IFNEC) <http://www.ifnec.org/>

5.7 Other Technology Issues Relating to Advanced Reactors

The current focus of efforts on Gen-IV systems has largely been determined by decisions taken during the initial phase of the GIF. However, the GIF as a body recognises that the technological, political and regulatory landscape evolves over time, and in a field such as nuclear technology in which R&D and the introduction of new designs will take decades it is therefore crucial to ensure that progress and new developments are kept under constant review. The events at Fukushima are one such example, and the impacts on future technology developments are still unclear; on the one hand the negative impact on the nuclear sector in general is self evident, though the resulting heightened importance of passive and inherent safety in future plants is clearly an argument in favour of Gen-IV designs.

In any case, if there is consensus within the GIF to divert attention towards other concepts or technologies, or concentrate on only a sub-set of the current selection, then research collaborations will be adapted accordingly. Issues that have arisen recently, and on which the GIF has given its collective opinion, concern the thorium fuel cycle and SMRs (small and medium-sized, or small modular, reactors).

Concerning SMRs, the GIF could find no identifiable rationale that would cause the forum to treat SMRs as a separate technology, though most of the technology options under study could involve an SMR concept (see Figure 5). There are already operating in the world a large number of reactors classified by the IAEA as SMRs, and recently there has been increased interest in SMRs in a number of countries, including the USA, in particular with regard to integral PWRs such as the Westinghouse IRIS design. Clearly advanced technology could also be of benefit to SMR concepts, and GIF needs to remain aware of SMR initiatives; if there are viability and performance issues that can be addressed through the GIF collaborative R&D framework then specific projects can be proposed by GIF members.

The use of thorium in nuclear fuel has been a topic of interest for decades. Reactors have already operated with Th-U fuel in the past, notably the Shippingport Light Water Breeder test reactor in the USA from 1977–82. India in particular maintains a strong interest in thorium reactors today in view of its substantial thorium reserves. The GIF opinion is just one of a number of authoritative views from a range of national and international bodies, including the IAEA.¹⁵⁰ The fundamental question is whether thorium represents a better choice of fertile material than depleted uranium (²³⁸U). There are many aspects and angles to this question, involving issues such as the relative merits of ²³³U and ²³⁹Pu as a fissile fuel, proliferation resistance, cost, radiation protection, availability of resources, and management of minor actinides. The GIF already considers the MSR operating with a U-Th fuel cycle as a potential long-term alternative to U-Pu fuelled FNRs, provided technical and commercial viability can be proven. In addition, it acknowledges that a first application of thorium-based fuels could be in countries with excess plutonium, since the use of a thorium fuel matrix would allow maximum destruction of plutonium and minimised generation of minor actinides. The use of thorium fuel in symbiotic generating fleets of thermal and fast neutron reactors is also appealing in terms of resource utilisation. However, all these options would require significant investment in research and facilities, as well as the performing of comprehensive feasibility and economic studies. In the end, the GIF decided that the general strategy regarding use of thorium should be discussed in forums such as INPRO, and that further consideration of the use of thorium fuel in the six GIF systems under study should be left as an option to be decided by the relevant System Steering Committee.

¹⁵⁰ International Atomic Energy Agency (IAEA) (2005): 'Thorium Fuel Cycle — Potential Benefits and Challenges' IAEA-TECDOC-1450, IAEA: Vienna http://www-pub.iaea.org/mtcd/publications/pdf/te_1450_web.pdf

Conclusions and Recommendations

□ **If the UK is serious about embracing nuclear technology in the long term, then it needs to stay abreast of technological advances that are likely during this period. Since the nuclear industry, left to market forces, is probably unable or not prepared to cope with the long timescales or the risks involved in the development of radically new reactor designs, most countries with sizeable civil nuclear power programmes have allocated significant public R&D funding in order to support the attaining of long-term energy objectives and to ensure their long term interests in nuclear technology are protected. The recently published House of Lords Science and Technology Select Committee Report on Nuclear Research and Development Capabilities underlined the need for a similar approach in the UK. Moreover, if a hi-tech sector such as nuclear science and engineering is to attract top quality students then it needs to offer an exciting and dynamic R&D environment at the cutting-edge.**

The level of talent will have a bearing on a range of crucial issues, not least of which are those directly concerned with nuclear safety. In this regard, countries looking to phase out nuclear technology may encounter serious problems in attracting professionals of sufficient calibre. Even though current collaborations being fostered by the GIF are at the level of pre-conceptual design research, the following steps of demonstrator design and construction will probably mark a return to more protectionist approaches and the increasing involvement of Industry. In this regard, unlike most of the other GIF

members, the UK no longer has an indigenous large scale nuclear construction industry to protect.

- **The opportunities offered by the membership of GIF and, to a lesser extent, INPRO, need to be seen in a wider context, namely the possibility of forming alliances and shaping the future in collaboration with the world's leading nuclear players. In this process, the UK would be able to ensure that the skills and supply chain it still retains have the best chance of being exploited in the future.**
- **It is unwise to assume that UK interests can be represented via Euratom participation. Though current and future Euratom projects on Gen-IV topics can offer the possibility of cooperation and information exchange of benefit to a range of UK organisations, Euratom funding will remain limited and the selection of topics is on the basis of competitive calls for proposals, with no guarantee that issues of particular importance to the UK will be covered.**

Furthermore, since Euratom Framework Programmes have to be adopted in Council in unanimity, their content is effectively in the hands of other EU member states with diametrically opposite views on nuclear power to those in the UK. Already this has led to a significant tightening of the conditions allowing funding on advanced technology projects in the current Euratom Framework Programme for the years 2012–13.

In comparison with comparable EU member states, the UK is underperforming as far as involvement in collaborative European research on Gen-IV topics is concerned. Though the participation of a number of UK universities, especially in projects dealing with more fundamental areas of nuclear science, is to be welcomed, other key actors are generally under-represented, either for reasons of lack of funding or competences, though this also may reflect current national strategy / priorities. Nonetheless, UK players are represented in ESNII, and this with the endorsement of the UK government ministries involved in the SET-Plan governance bodies. Current activities are relatively low key and limited to coordination activities.

The UK is an important player in fusion research, and the current evolution of the fusion energy research programme from basic plasma physics towards more power plant technology development bodes well for increased collaboration and cross-fertilisation with Gen-IV research. Common issues such as liquid metals, helium cooling, remote handling, neutronics, diagnostics and above all material science would benefit from a more integrated approach. Already much of the fundamental research on materials carried out in UK universities and funded through Research Council grants could be of benefit in either the fusion or fission sector, and this emphasis on cross-cutting research is also likely to be a feature of future research programmes at the European level.

If collaborations within the GIF are a good guide, then the SFR shows the greatest potential as a Gen-IV FNR system for deployment in the medium to long term.

Conclusions and Recommendations (continued)

However, this is a GIF system in which Euratom participation is quite low, and as a result there are very few Euratom projects dealing specifically with SFR technology issues, limiting even further the possibility for involvement of UK partners. Direct involvement of the UK in GIF could enable UK organisations to participate up to their full potential.

- **The recently signed civil nuclear cooperation agreement between the UK and France mentions closer ties in the area of research on Gen-IV systems, and this is seen as a very positive development. France is the leading civil nuclear power programme nation in Europe, with a comprehensive and well funded research sector, and the UK stands to gain a lot from being more closely associated.**

In exchange, the UK retains considerable experience and competences in a number of areas, in particular the fuel cycle and graphite and gas-cooled technology, and also can offer (albeit a limited number of) world class research infrastructures, in particular the Central Laboratory, managed by NNL at Sellafield. The UK has already demonstrated its willingness to contribute in these areas in the context of European research.

In the short to medium term there is potential for involvement in demonstrator plants under the ESNII umbrella, especially ASTRID, and it is here that enhanced collaboration with France could be particularly beneficial. Though the UK

has not been much involved in research on heavy liquid metal systems in the past, the Belgian decision to construct MYRRHA is a major development occurring on the UK's doorstep and could also offer opportunities for UK organisations, possibly as contractors in the design and construction, but also in the eventual exploitation, since this will be a unique research facility with many potential uses in a wide range of areas, including the development of advanced systems. However, in the UK's traditionally strong areas of gas technology, the prospects for ALLEGRO – the GFR alternative technology path proposed under ESNII – are far from assured, and the future evolution of HTR / VHTR technology in the European and international context is also uncertain.

- **If the UK were to accede to the GIF Framework Agreement and become a fully active GIF member, this must go hand in hand with a commitment to an indigenous programme of research and to participation in GIF collaborations in at least one of the current six systems under study. The decision regarding which system(s) to support must be based on a detailed analysis of current skills and competences in the UK, the future funding possibilities in these areas, the potential for UK supply chain involvement in eventual demonstrators and, in the longer term, commercial systems, and the prospects for future commercial deployment of the various systems. These aspects would also have to be considered in the light of overarching requirements regarding**

sustainability and energy security of the UK's energy sector as a whole.

As far as possible, the decision should also be consistent with policy options regarding choice of current fuel cycles (open or closed), plutonium disposition and management of high-level waste / spent nuclear fuel. The current UK Nuclear Fission Technology Roadmap¹⁵¹ prepared by NNL is a starting point for these considerations, but more detailed analysis would be necessary.

Even though Gen-IV decisions must be consistent with national strategy on nuclear as a whole, they necessarily concern the cutting edge of the sector and therefore involve a degree of technological (not to mention political and regulatory) risk. The possible returns in terms of business opportunities in the long term could be considerable, but there can be no guarantees. Therefore it is crucial to remain informed of global developments, in particular through membership of GIF and INPRO, to stay abreast of technology advances in the various systems in general, and to monitor closely the evolution of current, and the development of new, Gen-IV demonstrator projects, especially those in Europe. A coordinated and long term strategic approach, involving the UK's main research actors in close cooperation with key European players, is therefore a prerequisite to successful involvement in Gen-IV development on the world stage.

¹⁵¹ Energy Research Partnership (2012): 'UK Nuclear Fission Technology Roadmap: Preliminary Report' <http://www.energyresearchpartnership.org.uk/nucleartechnologyroadmap>



UK research and development in nuclear fission

One of the major challenges facing the UK in its bid to establish a credible future nuclear fission energy programme is the need to back that up with a fit for purpose R&D programme.

6.1 Background

The benefits of an R&D programme are manifold, but primarily it will provide the UK with the expertise needed to be an intelligent custodian of the existing nuclear power stations and deliver trained experts into the nuclear industry, crucial to maintaining and developing options for the nuclear fuel cycle, reactor safety and reactor life extension but also for providing the UK with a route to avail itself of future technological options. A further key element is the ability to retain regulator expertise and skills in decommissioning and waste disposal.

There are, necessarily, two components to this: the first is to secure a base-level research programme spanning both the university and industrial sector and the second is a need to develop a clear view of future developments of strategic importance to the UK civil nuclear power industry, which include consideration of legacy issues such as waste and the separated plutonium stockpile.

6.2 A Fit-For-Purpose Nuclear Research Base

The history of UK nuclear research and development has been turbulent. The early years saw the UK as world leaders in the exploration and development of nuclear technologies. This leadership was dramatically eroded in the 1980s and the UK now trails other leading nations (and even some that have no energy production by nuclear means, eg, Italy) in nuclear fission research.

Some of the earliest developments in nuclear energy have their origins in the UK. The nearly retired fleet of Magnox power stations were a UK innovation. Intrinsic to their design is safety – they used a gas coolant rather than water as in subsequent PWR and BWR reactors. In the UK there were 26 reactors of this basic design (although each differed slightly), including one of the world's first commercial power stations at Calder Hall. The last remaining Magnox power station is at Wylfa and is set for closure

in 2014. The Advanced Gas-cooled Reactor, an extension of the Magnox design, was developed in the 1960s and 70s in preference to the BWR, without proper regard to the greater impact of this design on the 'back end' decommissioning – a large part of the UK's potential decommissioning expenditure – and there are seven twin reactor stations still in operation in the UK, the last of which is currently scheduled to close in 2023. The final UK reactor, Sizewell B, was completed in 1995 based on a Westinghouse design and is the UK's only pressurised water reactor; it is due to cease operation around 2030, though lifetime extension is a possibility.

The heyday of UK nuclear energy lasted from the mid-1950s through to the late 1980s. During this period the volume of nuclear fission research was at its highest with close on 8,000 workers and a research budget of £300–400m per year.¹⁵² Together with incidents such as Three Mile Island and Chernobyl, the switch to cheap fossil fuel alternatives resulted in a

¹⁵² Sherry A. H., Howarth P. J. A., Kearns P. and Waterman N: 'A Review of the UK's Nuclear R&D Capability' (Prepared by the Dalton Nuclear Institute, National Nuclear Laboratory and Battelle, commissioned by the Technology Strategy Board in partnership with Materials UK and Regional Development Agencies) http://www.innovateuk.org/_assets/pdf/corporate-publications/uk_nuclear_r-d_review_web.pdf

de-investment in nuclear energy and nuclear energy research and an almost complete collapse in funding and the research base. BNFL was set up as a purely commercial operation with no incentive for non-profit activities; the 'Company Research Laboratory' set up in 1990 to expand the company turnover proved short-lived. The current national research remit is held by the National Nuclear Laboratory and comprises ~550 research staff¹⁵² (less than 10% of the original R&D base). The level of government funding for research in nuclear fission compared with that for all energy technologies, over the years 2007–2009¹⁵², is significantly less than in other nations exploiting nuclear power and this is even more striking when one compares the percentage power generation from nuclear in these countries. Even countries such as Germany, who have made significant

investments in renewable energy sources and with a long term ambivalent attitude to nuclear power, spends 7.4% of its national energy budget on nuclear fission research, and even Italy and Australia (who have no nuclear fission energy generation) spend a greater fraction on nuclear fission research than the UK (in 2009 it was only 1.5%). This level is more commensurate with a policy to phase out nuclear energy than an ambition to build new nuclear plants, perhaps even to a level outstripping current generating capacity. This contrasts strongly with the amount of money spent on fusion (£94m pa), 23% of the energy programme for 2010–11^{152, 153, 141}. This balance in part reflects the fact that fusion power is a long way from being commercially viable, and that there is a greater fission component industrially funded. Nevertheless, the comparison with other nations is revealing.

Although it is clear that the technological and scientific challenges in development of nuclear fusion as a realistic source of energy remain considerable and hence the level of research funding is necessarily high, there are significant scientific challenges in fission. For current generation power stations, these include the characterisation of materials used in reactor construction and fuels crucial in the bid to extend the operating life of currently operating nuclear reactors, optimisation and development of the fuel cycle and development of credible waste disposal methods. In large part these should be funded by Industry. However, looking forward to the future and so-called Generation IV reactors, these promise improved fuel cycle minor actinides thereby greatly reducing heat generation and long-lived radioactivity in spent fuel for disposal. It is also worth mentioning that hydrogen, as storable energy vector, can be

Figure 7a: Comparison between the percentage of national energy generated by nuclear power and the fraction of funding on fission R&D as a proportion of total energy funding

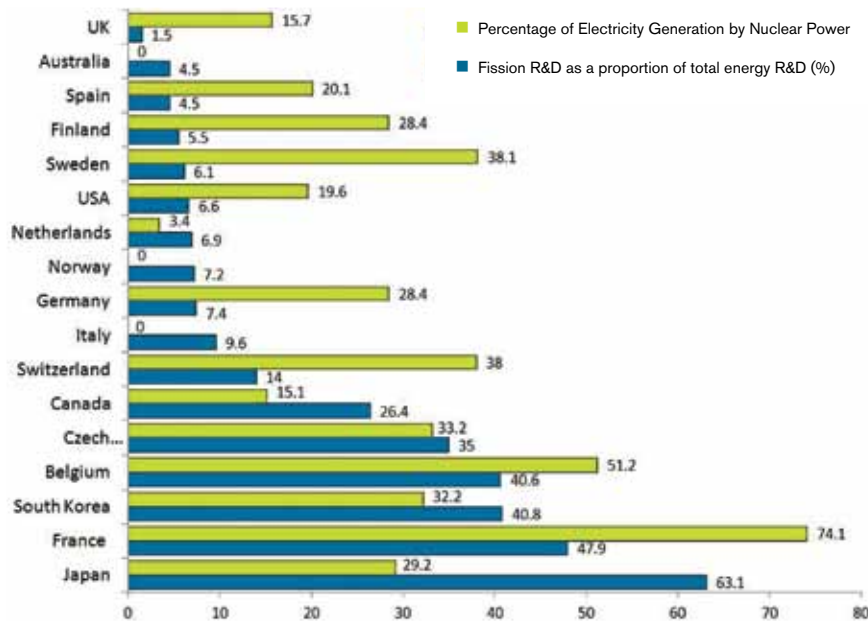
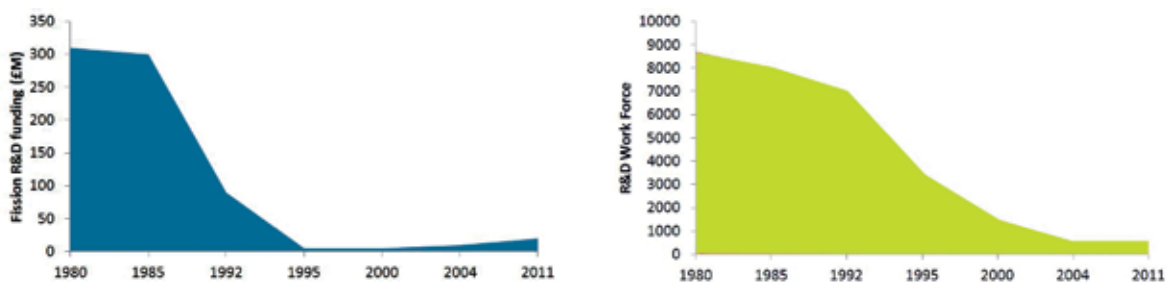


Figure 7b: The time profile of the UK fission R&D expenditure and manpower



¹⁵² Sherry A. H., Howarth P. J. A., Kearns P. and Waterman N: 'A Review of the UK's Nuclear R&D Capability' (Prepared by the Dalton Nuclear Institute, National Nuclear Laboratory and Battelle, commissioned by the Technology Strategy Board in partnership with Materials UK and Regional Development Agencies) http://www.innovateuk.org/_assets/pdf/corporate-publications/uk_nuclear_r-d_review_web.pdf

¹⁵³ Strategic Energy Technologies Information System (SETIS) <http://setis.ec.europa.eu/>

made 'on the back' of high temperature nuclear reactors. Key is the ability of these reactors to utilise the abundant isotope ^{238}U , through efficient breeding of ^{239}Pu , rather than the more scarce ^{235}U , thereby extending the potential period over which nuclear power could contribute to the energy economy. This future generation of reactors pose technological challenges, for example in the development of materials capable of withstanding radiation and temperatures in excess of those encountered in current day commercial reactors. There is a major international programme through the Generation-IV International Forum (GIF)¹⁴¹ involved in research related to such developments (See Chapter 5). Current UK involvement is at an extremely low level following the UK's withdrawal from GIF as an active participant and the existing role is merely as an observer.

6.3 Facilities

At present the UK research linked to fission is at a minimal level both in terms of funding and capacity. A recent OECD survey of nuclear energy research and test facilities¹⁵⁴ showed the UK to be woefully short of research facilities, and almost completely lacking in any which might be internationally competitive. Five facilities were identified. 1) The post irradiation examination (PIE) facility at Sellafield (to be decommissioned in 2040¹⁵⁵) operated by NNL. The facility is used primarily for PIE which includes fuel research; materials research; nuclear and radiochemistry research and in particular PIE of fuel rods, components and reactor structure, irradiated material conditioning. 2) The uranium active facility at Springfields, operated by NNL, in which fuels research, uranium chemical processing and radiochemistry is undertaken. 3) The Central Laboratory at Sellafield, which is the flagship facility of the NNL. The Central Laboratory offers experimental programmes and a wide range of analytical services on materials that cannot be analysed in any other facility in the UK. Future phases of commissioning include

plutonium/MOX laboratories and high active cells that have been designed to accept a wide range of gases and chemicals and to allow as wide a range of experiments as possible. 4) The Dalton Cumbrian Facility (DCF),¹⁵⁶ which is a radiation science facility including a cobalt 60 source, an ion beam accelerator and associated laboratories for radiation effects on materials and chemistry (yet to be completed and fully commissioned). 5) Radiochemistry laboratories at the Universities of Manchester and Loughborough. In addition, there are restricted facilities which the research community does not have access to such as: AWE, which has a fast burst reactor; VIPER, which is presently shutdown; and ASP, an accelerator based neutron generator system for 14 MeV neutrons.

As part of the House of Lords Assessment of Nuclear Research and Development Capabilities¹⁵⁷ the facilities at Sellafield were visited. These included the National Nuclear Laboratory's (NNL) **Central Laboratory**. Of particular significance are the Phase 2 and Phase 3 hot lab facilities. Phase 2 is currently being commissioned and is designed for plutonium-based research, for example relevant to MOX type fuels. Phase 3 was constructed over five years ago at considerable cost and is waiting to be commissioned (estimated to be £10–20m). These laboratories are designed to handle active materials such as radioactive fuels and would provide the ability to perform

fuel-cycle research. The particular edge that these facilities possess over and above other similar facilities found internationally is their flexibility. They possess a novel design which permits an element of 'plug and play'. Hot cells can be tooled up offline before being transported to the active location within the Phase 3 facilities. This kind of flexibility is ideal for a responsive research programme – ie, one in which the nature of the research is not predetermined and needs to be flexible over time. A number of UK universities (Manchester and Liverpool) have signed up for the new Third Party Access Agreement that enables universities to undertake active experiments in the NNL Central Laboratory and around six other universities have expressed interest. The UK has a long track record in fuel cycle developments which have resulted in the Sellafield MOX Plant (SMP) and the Thermal Oxide Reprocessing Plant (THORP). As such this is an obvious area for the UK to re-grow its research activities. The commissioning of the facilities is currently held up by an assessment of whether the facilities are commercially viable. This waste of a potentially vital national research facility was recognised in the House of Lords report and the Government response.¹⁵⁸

House of Lords Select Committee report stated: 'We recommend that the proposed Nuclear R&D Board should work with DECC, NNL, the NDA, BIS, the research councils and

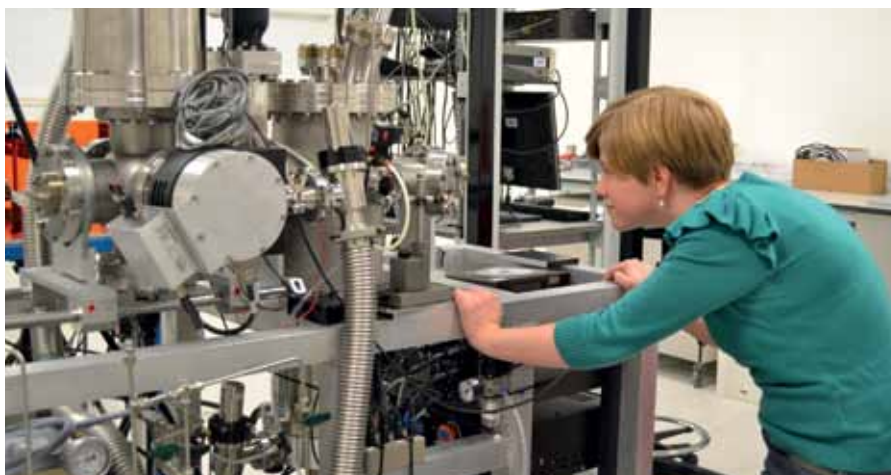
Figure 8: The National Nuclear Laboratory's Central Laboratory



¹⁵⁴ Nuclear Energy Agency (NEA), Organisation for Economic Co-operation and Development (2009): 'Research and Test Facilities Required in Nuclear Science and Technology' OECD: Paris <http://www.oecd-nea.org/science/reports/2009/6293-Research-Test-Facilities.pdf>

¹⁵⁵ United Kingdom Atomic Energy Authority (UKAEA) (2001): 'UKAEA's Decommissioning Strategy – September 2001, Vol. 2 Part 5: Windscale Site Strategy' <http://www.dounreay.com/UserFiles/File/archive/General/Volume%201%20-%20The%20Management%20of%20Nuclear%20Liabilities%20in%20UKAEA%20Part%205.pdf>

Figure 9: The Dalton Cumbrian Facility (DCF)

Figure 10: Postgraduate research into Dissociated Electron Attachment (DEA) to H₂O.

relevant industry groups to develop a business case to commission the Phase 3 laboratory at NNL as a national research facility for studying irradiated materials, taking into account its wider value to the nuclear sector and to the research community for research and, in particular, its contribution to training the next generation of experts and increasing the attractiveness of the UK as a destination for international research collaboration.¹⁵⁷

The Government responded: 'The Government acknowledges the significant current and potential future capability of NNL, and also recognises that it is important that NNL's activities continue to make commercial sense. We note the potential that NNL Labs could become part of a European network, and agree that commissioning of Phase 3 of the already world class Central Laboratory could enable research to be conducted on a range of highly radio-active materials.

NNL is already working with a wide range of potential users of the Phase 3 facility, both in the UK and overseas, covering the full spectrum of potential uses. This is to understand their requirements and to see if a business case can be developed to commission the facility. Subject to the outcomes of this work, the Government will consider further the business case, technical challenges and options for commissioning the laboratory.¹⁵⁸

The conclusion is that there is broad consensus that these facilities offer a research capability which could go some way to re-establishing the UK's research capacity in the area of the fuel cycle.

¹⁵⁷ House of Lords Nuclear Research and Development Capabilities – Science and Technology Committee (18 July 2011) 'Appendix 5: Visit to the National Nuclear Laboratory (NNL), Nuclear Decommissioning Authority (NDA) And Sellafield Ltd' <http://www.publications.parliament.uk/pa/ld201012/ldselect/ldscstech/221/221117.htm>

¹⁵⁸ 'Government Response to the House of Lords Science and Technology Select Committee Report: 'Nuclear Research and Development Capabilities'' <http://www.parliament.uk/documents/lords-committees/science-technology/NRDC/GovtResponseNuclear.pdf>

However, an essential element of this conundrum is the role of the National Nuclear Laboratory. The National Nuclear Laboratory is a commercial, customer funded, Government Owned, Contractor Operated (GoCo) organisation. As such it operates research based on a commercial model rather than one which is exclusively driven by national strategic and research interests. This places the National Nuclear Laboratory in a unique position, unlike international counterparts, which means that research facilities should also be operated on a commercially viable basis. This can be contrasted with other RCUK facilities such as ISIS and DIAMOND which are operated by the Science and Technology Facilities Council (STFC) via research council funding, accessed competitively on a case by case basis by researchers and free at the point of access. This mechanism gives university researchers access to world-class neutron scattering and synchrotron radiation facilities. **If the Phase 2 and Phase 3 laboratories are to become national user facilities then an alternate funding model will be required. This could involve direct funding to NNL to operate them as non-commercial user facilities, with non-academic access being charged for at a commercial rate.** As with DIAMOND, NNL could be a partner in large EU consortia with commercial rate 'access charges' written into the EU costing model. As a by-product these approaches may further foster closer industry-academic collaboration.

A further national facility which will foster a re-growth in fundamental materials and applied nuclear research is the Dalton Cumbrian Facility (DCF).¹⁵⁶ The facility is

presently being commissioned as a £20m joint investment between the University of Manchester and the NDA. The heart of the facility is a 5MV ion accelerator (Pelletron) capable of supplying 10MeV protons and 15MeV helium ions as well as a variety of partially stripped heavy (eg, metal) ions. This will be used for materials irradiation and radiation chemistry to explore changes in characteristic properties of materials used in the nuclear industry. Such work is important in, for example, reactor life extension research. Although reactors produce neutrons rather than protons it is possible to refine models of radiation damage of ions which may then be applied to neutron damage. Similar facilities exist elsewhere, for example in the US, and the University of Birmingham is developing a facility based around 40 MeV protons. Ultimately, testing using neutrons provides the most accurate characterisation of nuclear materials and to this end the Jules Horowitz Reactor, being built by the CEA at its Cadarache site in the South of France, will provide the premier materials testing facility for advanced nuclear technology. Construction is due to be completed in 2014 and though most of the funding is French, 20% is provided by EU partners (Spain, Belgium, Finland, the Czech Republic and Euratom).

The DCF has the ambition to become a national user facility which credibly would become a focus for the regeneration of irradiated materials research programmes. In order to operate such facilities there are running costs, which reach beyond the original construction budget.

Recommendations

- **As part of the development of a suite of competitive research facilities it is important that these are genuine user facilities. As such there needs to be an appropriate national funding model for fission research in which operating costs for national facilities are provided as a quid-pro-quo for securing access by end-users, in particular university research groups.**
- **The development of the Phase 2 and 3 facilities at the NNL's Central Laboratory would provide a much needed opportunity for the UK research community to engage in nuclear fuel and nuclear fuel cycle research. This may mean that the rationale for operating the facilities should be research opportunity and impact rather than commercial benefit. This would have implications for how NNL operate and might be inconsistent with their current mission.**

6.4 Future Facilities

In terms of nuclear energy, the EU – with the unanimous support of member states who all contribute to the EU budget – has made a major financial commitment to the construction of the ITER fusion reactor. ITER is to study plasmas under conditions relevant for future power plants. However, it will not produce any electrical power. The timescale for these studies is 2020–2030. Beyond that it is planned to build DEMO which could eventually deliver power into the grid around 2040–50. There are many technical issues to overcome most notably those associated with the development of new materials. As observed earlier, the UK's commitment to fission energy research is minimal and pales into insignificance when compared to international partners. In the case of the Jules Horowitz materials test reactor, the French atomic energy commission (CEA) is funding 50% of the total €630m construction cost, with the remainder coming from EdF (20%), Areva (10%) and 20% from European partners.¹⁵⁹ The Belgian Government has committed to funding up to 40% of the €960m investment in MYRRHA, to be constructed at its national nuclear research centre at Mol. The facility is a subcritical reactor driven by a proton accelerator and is scheduled for operation in 2023.¹⁶⁰ In evidence to the House of Lords enquiry it was pointed out that 'the US had recently added \$120m a year to their programme and France recently announced an additional €1bn for new demonstrators for advanced reactors'.¹⁶¹ The UK is a long way behind the curve in terms of research infrastructure. This has placed the research community at an extreme disadvantage in terms of engagement in initiatives such as GIF. At the heart of creating a vibrant internationally competitive research community in nuclear fission lies the need to attract bright young

people who see creative opportunities in research. In this regard nuclear fusion has been extremely successful thanks largely to a well coordinated effort at European level and an sufficient level of funding through a combination of Euratom support and national resources. A successful future UK research programme in fission also needs to be based around areas of innovation and challenge. In this regard the scientific challenges around Generation-IV type reactors have great potential. These are summarised as: sustainability, economics, safety and reliability and proliferation resistance and physical protection.¹⁶²

There are six different potential reactor designs and many different design challenges. To provide a foothold in Gen-IV research the UK needs to invest both in research and research facilities. One that stands out is the development of new materials capable of operating at the higher temperatures and neutron energies mandated in these designs. There is thus a need to test new materials, eg, silicon carbides and ODS steels, at high temperatures and with neutrons which have an energy spectrum which is different from that required for characterisation of materials for current thermal reactors.

In the case of materials there is a remarkable confluence of research interests. One of the outstanding challenges in fusion research is the development of materials which can withstand the flux of high energy neutrons produced in the d+t fusion reaction. For fast reactors and fusion the materials characterisation needs to be performed in similar radiation environments. In addition, the ideas currently being explored by the UK fusion community to develop an accelerator based facility to produce a high flux of fast neutrons could form the basis for a fusion+Gen-IV materials research programme.

In a second strand, the characterisation of irradiated materials using precision techniques can lead to a fundamental understanding of the processes through which irradiation damage changes the properties of materials – which leads to improved modelling and predictive power. A very interesting innovation would be the coupling of an ion-irradiation facility (à la the DCF) with the ability to provide in situ (ie, real time) characterisation of the degradation/transformation of the material. This could be done by constructing an ion-irradiation facility on a synchrotron beam-line. Moreover, the ability to perform X-ray diffraction or X-ray tomography on active nuclear materials would be a considerable advance. There are discussions ongoing at Brookhaven National Laboratory (BNL) to use the Brookhaven light source for such studies,¹⁶³ and similar discussions are being held at Argonne National Laboratory.¹⁶⁴ The existence of DIAMOND,¹⁶⁵ which is a world-class light source, could provide the UK with an opportunity to take a leading role within Europe on the fundamental characterisation of nuclear materials through ion-irradiation techniques. This would be entirely complementary to the development of the Jules Horowitz facility in France.

¹⁵⁹ World Nuclear News (01 July 2008): 'European materials test reactor progresses' http://www.world-nuclear-news.org/NN-European_materials_Test_reactor_progress-0107088.html

¹⁶⁰ World Nuclear News: (01 December 2010) 'Myrrha picked as European research infrastructure' http://www.world-nuclear-news.org/NN-Myrrha_announced_as_European_research_infrastructure-0112104.html

¹⁶¹ House of Lords Science and Technology Committee – Third Report (2011): 'Nuclear Research and Development Capabilities' – 'Chapter 6: Keeping the Nuclear Energy Options Open' <http://www.publications.parliament.uk/pa/ld201012/ldselect/ldscitech/221/22102.htm>

¹⁶² GIF and Generation-IV http://www.gen-4.org/PDFs/GIF_Overview.pdf

¹⁶³ Brookhaven National Laboratory: Synchrotron X-ray Studies of Advanced Nuclear Energy Systems at NSLS II <http://www.bnl.gov/radbeam>

¹⁶⁴ International Atomic Energy Agency (IAEA): 'Enhancement of Accelerator Based Real-time Methods in Development and Characterization for Materials for Energy Applications' Conference January 2011, Argonne National Laboratory, Illinois, USA <http://www-pub.iaea.org/mtcd/meetings/Announcements.asp?ConfID=40585>

¹⁶⁵ Diamond Light Source <http://www.diamond.ac.uk>

Conclusions and Recommendations

- The UK nuclear fission research community and research councils should open up a dialogue regarding the development of future research facilities which create world-class and world-leading research opportunities. These would provide the mechanism to grow the UK's research base both in terms of expertise and volume and the ability to attract talented new researchers into the field.
 - The area of nuclear materials research is an area of strength for the UK. The development of new facilities to characterise materials for both current and future generation nuclear reactors is important. These could be coupled to the DIAMOND light source or with the ambitions of the fusion community to develop a materials irradiation facility for fusion materials.
 - With limited resources (investment, facilities and people), any future national R&D programme will need to be appropriately focussed on a few key areas. A national committee (akin to that recommended by the Royal Society) should oversee that programme of work. Determining the priority areas/activities needs to be endorsed by the UK Government as part of any future road-mapping exercise. Considerations of the prioritisation should include:
 - The development of intellectual property, products and services for the UK nuclear industry both in the domestic and international setting.
 - To develop the UK as an intelligent customer (assuming other countries will develop the technologies).
 - Skills maintenance and development for industry and regulators.
 - Political/strategic reasons for a conscientious nuclear nation.
 - Regardless of the reasons, it clearly makes sense to work on those technologies that are likely to be successful, either because:
 - They offer the best prospect of a return on investment.
 - They have the best chance of gaining access to intellectual and financial gearing.
 - They need skills and knowledge relevant to the technologies that will be deployed in the future.
 - The guiding principles for UK participation in international R&D programmes are likely to include:
 - Avoid spreading modest resources too thinly.
 - Extract maximum benefit from past and current investments.
 - Seek a balanced portfolio capable of addressing a range of future demands, but with a minimum of technology development.
 - Build on available UK expertise and capabilities, especially where these are key to maintaining strategic options.
 - Ensure that at least one 'sustainable' system is included (ie, a fast reactor system).
- The review being conducted by Nuclear Research and Development Advisory Board into nuclear R&D in the UK, chaired by the Government's Chief Scientific Adviser Sir John Beddington, is a most welcome development.

7

A roadmap for nuclear energy, nuclear research and the fuel cycle

The issues connected with nuclear energy are long term and have a historical imperative (through legacy waste and the plutonium stockpile). The complexity of the arguments means the need for a roadmap is even more important in this area than other parts of energy policy – joined up thinking is key to avoiding costly investments which turn out to be white elephants.

This approach is also an essential starting point to ensuring that there are the appropriate skills bases in research, construction, operation and maintenance to underpin the UK's ambitions. As outlined in Chapter 4 of this report, coherent oversight was historically provided by BNFL but there is currently a disconnect between short term economic and long term strategic policy in regard to both nuclear technologies and the nuclear fuel cycle. At the moment a roadmap is severely lacking.

There have been many calls for such a roadmap, the last of which came in the House of Lords Select Committee report¹⁶¹: 'We recommend that, as part of its overall nuclear energy strategy, DECC should lead the development and implementation of a long-term R&D roadmap in collaboration with industry, academia, the [Culham Centre for Fusion Energy] CCFE and NNL to ensure that the UK has adequate R&D capabilities and the associated expertise to keep a range of nuclear energy options open up to 2050 and beyond.' In turn the Government acknowledged the

need for a roadmap¹⁵⁸ and set out the steps to put such a roadmap in place – by the end of 2012. This process has started with the fission roadmap developed by the Energy Research Partnership (ERP). **It is vital that the development of a roadmap should continue to be in collaboration with all of the stakeholders: industry, government and academic.**

Such a roadmap is pressing as the following examples extracted from Chapter 4 reveal. The preferred government option for reducing the ~100 tonne stockpile of plutonium that the UK oversees is MOX fuel. This involves mixing the plutonium with uranium and recycling in reactors as fresh fuel. The UK has in-depth experience in developing MOX fuel, but the MOX plant at Sellafield has now been closed – as a consequence of its very poor economic performance and fuel production. The Royal Society's report on 'Fuel Cycle Stewardship in a Nuclear Renaissance'¹³⁶ suggests the construction of a new MOX plant. This is a reasonable conclusion in view of the fact that

both the EPR and AP1000 have the capacity to use MOX fuel, ensuring the plutonium was either consumed in the reactors or made much more proliferation resistant by virtue of the intense radioactivity of the spent fuel. However, the Generic Design Assessment, which is the process by which the EPR and AP1000 are being licensed, and the regulatory justifications for these reactors under the process for Justification of Practices Involving Ionising Radiation Regulations 2004, have been performed on the basis that the reactors will not use MOX fuel. The adaption to use MOX fuel at a later date would require further review and licensing and possibly modification – and would involve significant additional cost. Furthermore, the Government's view on the future value of the plutonium for use in fast reactors is now being considered, whereas previously anything other than MOX fuel was excluded from consideration. Here the proposal is to build a suite of dedicated fast reactors. Recently the Nuclear Decommissioning Authority (NDA) agreed with GE-Hitachi to further study the use of the PRISM¹⁶⁶ reactors

for plutonium management.¹⁶⁷ The NDA had previously concluded that such a technology was unlikely to be available within the timescales necessary for disposition of UK plutonium. However this is now being tested by a review to establish whether the design is licensable in the UK and whether any utility will credibly adopt it. Similarly the THORP fuel reprocessing plant is due to close. The UK has built up much expertise in fuel recycling on an industrial scale. The loss of that expertise will close off options regarding the kind of fuel cycle the UK is able to exploit in the future – being limited to ‘once through’ where the fuel is used in the reactor and then sent to a repository, as opposed to being reprocessed and the unused uranium and plutonium recycled and reused in fresh fuel, with an associated potential cost saving (Chapter 4).

There are also the longer term questions of what size of nuclear fleet the UK is building. Is it to replace the existing nuclear generating capacity or is it to increase that capacity to close to 40% of the UK’s electricity production? The currently proposed reactors have a lifespan of approximately 60 years. Does the UK plan to develop/build next generation reactors (Gen-IV) with greatly increased sustainability, increased efficiency and safety, with the ability to recycle spent fuel from current reactors and burn long-lived high activity waste? Will the UK be involved in developing such reactors or will it be an intelligent purchaser of the technology? Should the UK ‘buy in’ to overseas Gen-IV development programmes, or consider joint development with overseas consortia?

The lack of direction may reflect a need to keep options open, but will also create problems as technological expertise is lost and options close owing to a lack of coherent planning and thought. A roadmap would help clarify the options, crystallise the areas for future investment, both in terms of infrastructure and research capacity,

and provide an incentive for our young talent to develop their careers within the UK instead of following opportunities overseas.

Examples of best practice in terms of developing a credible strategy lie close by. France has a well developed strategy for the development of nuclear energy up to 2040¹⁶⁸ with a programme to develop a Gen-IV demonstrator sodium-cooled fast reactor, building on the experience of Phénix and Superphénix but with more advanced technology resulting from on-going R&D. In addition, research is continuing on the gas-cooled fast reactor as an alternative technology, though plans for moving to the demonstrator stage are much less advanced. New fast reactor technologies will form the basis for future exports to build on the existing French market presence through the EPR reactor. Overall nuclear policy is established by a high level **Nuclear Policy Council** (Conseil de Politique Nucléaire – CPN) chaired by the President and on which the Prime Minister also sits. At the working level, the **Strategic Committee of Nuclear Power** (Comité Stratégique de Filière Nucléaire), established by the CPN, is chaired by the Minister of Energy and brings together all nuclear players in France, including Industry, the Unions, as well as R&D and education and training actors. In general, there is strong recognition of the importance of public information and education as well as the economic potential associated with nuclear power technologies. It is unlikely this model would be ideally suited to the UK situation, but nonetheless there are important lessons here for other countries and the UK Government would be well advised to consider both the French as well as other national models for defining and implementing nuclear policy in the dual national interests of sustainable energy and energy security. In this regard, it is worth underlining that the House of Lords report suggests the formation of a UK expert body.

Conclusions and Recommendations

- The formation of a clear long term policy on the scale of new nuclear build and the timescale is vital.
- The development of a policy on the nature of the fuel cycle envisaged for the future and the mechanism for management of plutonium is pressing. If the use of MOX fuel in EPR and AP1000 reactors is the preferred option, then the licensing implications need to be carefully considered.
- The formation of a high level policy body with representatives from NNL, NDA, Industry, DECC and also academia to steer policy beyond the development of a roadmap should be considered.

The first steps in the development of a roadmap have been embarked upon through the ERP-National Nuclear Laboratory’s ‘UK Nuclear Fission Technology Roadmap’ published in February 2012.¹⁵¹ This outlines the challenges associated with the replacement and expansion scenarios and the critical decisions which need to be taken on the timescale of the next five years. This menu of possible options provides an excellent basis for taking decisions in the formation of a roadmap for the future of nuclear energy.

¹⁶⁶ GE-Hitachi: ‘PRISM Sodium-Cooled Reactor’ http://www.ge-energy.com/products_and_services/products/nuclear_energy/prism_sodium_cooled_reactor.jsp

¹⁶⁷ I-Nuclear (April 3, 2012): ‘UK NDA signs contract with GE Hitachi for study on Prism reactors for Pu disposition’ <http://www.i-nuclear.com/2012/04/03/uk-nda-signs-contract-with-ge-hitachi-for-study-on-prism-reactors-for-pu-disposition/>

¹⁶⁸ World Nuclear Association: Nuclear Power in France <http://www.world-nuclear.org/info/inf40.html>

The future of waste disposal

8.1 Background

The UK has generated a substantial amount of nuclear waste from its earlier nuclear programmes, both civil and military. The volumes of intermediate and high-level waste to be disposed of from these activities are estimated to be 287,000m³ and 1,020m³ respectively.¹⁶⁹ By comparison, the volumes associated with the operation of the planned new reactors will be very small – these plants will produce less irradiated fuel per unit of electricity generated, and unlike the UK's historic Magnox reactors and AGRs are not associated with large volumes of graphite waste.

The disposal of this waste in a safe and environmentally responsible manner presents both a scientific and engineering challenge. The internationally accepted solution, certainly in the expert community, and the one endorsed in the CoRWM (Committee on Radioactive Waste Management) 2006 report to the Government and reflected in the Managing Radioactive Waste Safely White Paper 2008,¹⁷⁰ is that the most radioactive and long-lived wastes, such as irradiated nuclear fuels or the residues from the reprocessing of this spent fuel, should be sealed in a deep repository in an environment that will remain geologically stable over the period during which the waste continues to present a radiation hazard, which could be tens of thousands of years. This 'confine and contain' strategy, which ensures that the radiation decays to safe levels before there is any degradation in the containment barriers, is the principle behind management of all

radioactive waste, whether it concerns short-lived wastes that are currently disposed of in engineered surface or near-surface repositories in many countries, or the much more radioactive and longer lived nuclear wastes destined for geological disposal. In the latter case the disposal should be at a depth sufficient to avoid accidental man-made interference and possible disruption by future glacial activity, which is considered to be at least 400–500m. The repository would stay open for around 100 years, but eventually would be sealed leaving the waste in a passively safe condition without the need for further active measures by future society. In this way, no burden is passed on to future generations that have not benefitted from the electricity produced by the nuclear power programme, though it is likely that some form of long term stewardship will be undertaken for many years post-closure.

The Nuclear Decommissioning Authority (NDA) timeframe for the construction and operation of a future Geological Disposal Facility (GDF)¹⁷¹ foresees:

- Construction of the facility by 2040 and acceptance of intermediate level waste at this point.
- The facility would then be licensed, following a safety assessment process, to accept legacy high level waste and spent fuels from existing power stations around 2075.
- From 2130 fuels from the new-build power stations would be transferred from their current storage sites (eg, cooling ponds).
- The facility would be closed in 2175.

Presently the NDA is developing the scientific basis for a geological waste repository together with the process of engaging with communities who may have a potential interest in hosting the facility.

One possible design for the waste repository under consideration is based on the KBS-3 concept developed in Sweden and Finland, which is appropriate for high strength rock, eg, granite (see repository schematic and disposal canister, Figure 11). In the Swedish and Finnish high-level waste (spent nuclear fuel) management strategy, the spent fuel is first allowed to cool for 30 years in intermediate storage (cooling ponds), before being encapsulated in an iron and then an external corrosion resistant copper canister. After sealing, the canisters are deposited in boreholes 8m deep and with a diameter of 2m drilled in the floor of disposal tunnels, situated 500m underground in crystalline rock. The disposal holes are sealed with bentonite clay to provide an additional impervious buffer or barrier. Once the disposal facility is full, the tunnels are backfilled and sealed. After 100,000 years, the radioactivity of the spent fuel will have decayed to approximately the same level as that of the ore body from which the original uranium was mined.¹⁷² With a high level of confidence, the geological environment is expected to remain stable for these periods of time, thereby ensuring the nuclear material remains confined and isolated from the biosphere until the radioactivity has decayed to safe levels. Host rocks other than granite are also being actively investigated in Europe – eg, Opalinus clay in Switzerland, Callovo-Oxfordian

¹⁶⁹ Report prepared for the Department of Energy & Climate Change (DECC) and the Nuclear Decommissioning Authority (NDA) by Pöyry Energy Limited (2011): 'The 2010 UK Radioactive Waste Inventory: Main Report' Nuclear Decommissioning Authority: Cumbria <http://www.nda.gov.uk/ukinventory/documents/Reports/upload/2010-UK-Radioactive-Waste-Inventory-Main-Report.pdf>

¹⁷⁰ Defra, BERR and the devolved administrations for Wales and Northern Ireland (2008): 'White Paper: Managing Radioactive Waste Safely. A Framework for Implementing Geological Disposal' TSO (The Stationery Office): Norwich <http://mrws.decc.gov.uk/assets/decc/mrws/white-paper-final.pdf>

¹⁷¹ Nuclear Decommissioning Authority (March 2010): 'Geological Disposal, Steps Towards Implementation', NDA Report no. NDA/RWMD/013 Nuclear Decommissioning Authority: Didcot <http://www.nda.gov.uk/documents/upload/Geological-Disposal-Steps-Towards-Implementation-March-2010.pdf>

¹⁷² Manson B., Pigford T.H., Levi H. (1981): 'Nuclear Chemical Engineering' McGraw-Hill, Toronto

¹⁷³ Nuclear Decommissioning Authority (December 2011): 'Geological Disposal: Review of Options for Accelerating Implementation of the Geological Disposal Programme', NDA Report no. NDA/RWMD/083 Nuclear Decommissioning Authority: Didcot <http://www.nda.gov.uk/documents/upload/Geological-Disposal-Review-of-options-for-accelerating-implementation-of-the-Geological-Disposal-programme-December-2011.pdf>

Clay in France, and the Boom clay in Belgium – and similar deposits may also be exploited for the UK GDF.^x In the US, the Waste Isolation Pilot Plant (WIPP), constructed in a deep salt deposit, has already been operating for many years as the disposal site for so-called trans-uranic waste from the US defence programme. Though this waste is not categorised as high level, considerable research has been undertaken in Germany to develop the concept of high-level waste/spent fuel disposal in salt, in particular at the Gorleben facility.

8.2 Key Issues

8.2.1 UK Policy

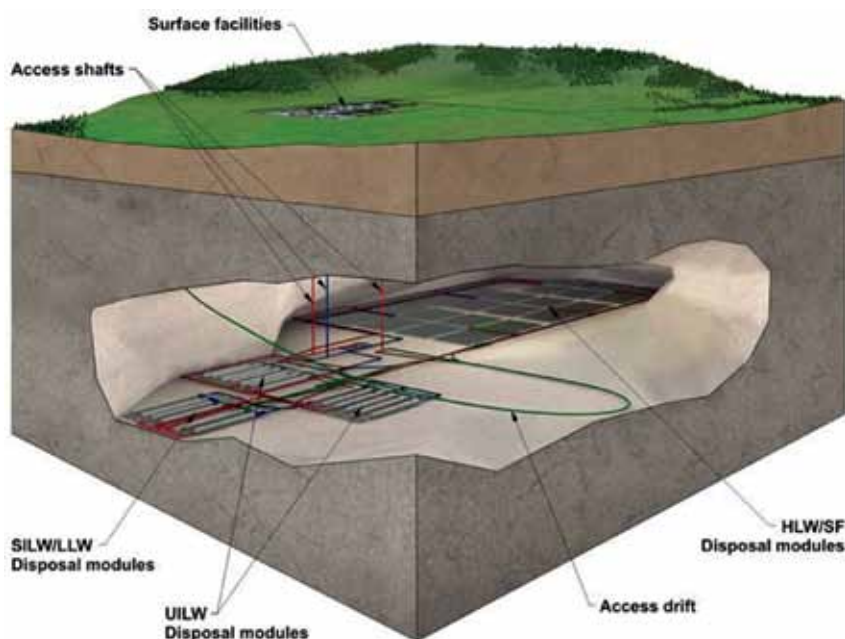
In keeping with international thinking, deep geological disposal of intermediate and high-level waste is the preferred option in England (though not in Scotland, where long-term interim storage – often categorised as a ‘wait and see’ strategy – appears to be the current position). There are a number of issues associated with realising such a project. These include the challenges associated with public

opinion, identifying a suitable host site, and creating an economically viable plan for construction and operation. The high level government policy for site identification and selection is set out in the 2008 White Paper ‘Managing Radioactive Waste Safely’.¹⁷⁰ A 2012 review of UK policy, published by the University of Sussex,¹⁷⁴ documents the patchy history associated with geological waste disposal in the UK and some of the lessons that have emerged. The approach to site selection is based on voluntarism and partnership, as has proven successful in Sweden.

Figure 11a: Spent Fuel Disposal Capsules Developed for the Swedish Disposal Concept



Figure 11b: Schematic Geological Setting for a UK Geological Disposal Facility



In the UK the first stage of the process has resulted in three councils (all in West Cumbria) putting forward an ‘expression of interest’. The British Geological Survey’s (BGS) initial unsuitability screening of the subsurface identified regions within those areas that are potentially suitable. The next step is to confirm the community Decision to Participate and proceed to scientific studies of the potential site (desk based).

This will involve a Multi-Criteria Decision Analysis that will inform the selection of Potential Candidate Sites (PCS). At the present stage, the NDA Disposal System Safety Case is very broad and the inventory of wastes for disposal is itself not finalised. The weight given to geological and hydrogeological expert input to the PCS selection is not clearly defined. Moreover, the potential roles that biogeochemical processes may contribute over extended timescales have to-date been neglected. There are signs that other communities are also considering this option (eg, Shepway District Council in Kent¹⁷⁵).

‘In order to give confidence to new nuclear build, this process needs to be more clearly defined and the responsibility for the cost associated with future developments in the process needs to be clearly set out.’ (The current position as of March 2012 examined in a recent report¹⁷⁴)

The voluntarism approach is clearly desirable as it provides the optimal way of engaging with the local communities, but it is likely to restrict consideration to a limited geographical area and to constrain the disposal concept to one geological setting.

¹⁷⁴ Mackerron G (2012): ‘Evaluation of Nuclear Decommissioning and Waste Management’ Report commissioned by DECC March 2012. University of Sussex <http://www.theengineer.co.uk/Journals/2012/03/02/e/1/4496-mackerron-report-evaluation-of-nuclear-decommissi.pdf>

¹⁷⁵ BBC News (16 May 2012): ‘Kent nuclear waste bunker proposal considered’ <http://www.bbc.co.uk/news/uk-england-kent-18086988>

Recommendation

- **The current UK strategy of seeking volunteering communities to host a geological repository has been found to be successful elsewhere. However, there is a fundamental weakness if only one community steps forward since this limits options and potentially increases costs if additional engineering is needed because of more challenging geological conditions. The Government together with the NDA need to reconsider whether enough information is being provided to potential host communities and whether the incentives for them to engage in the site selection process are sufficiently attractive.**

8.2.2 The Scientific Case

There are two key aspects to demonstrating the scientific case for the Disposal System Safety Case (DSSC) developed for a GDF. Firstly, it must be robust in that the performance of the barriers isolating the waste from the human environment is clearly demonstrated. Furthermore, this demonstration must be widely accepted by the scientific community and society. Such a broad consensus requires a relatively simple geological setting and well established understanding of the basic processes scientifically relied upon. Moreover, it is necessary to demonstrate how the site can be characterised from available surface and in situ investigation techniques and how the possible presence of features, eg, fissures, which would compromise the DSSC can be ruled out.

A second requirement, when relying on predictions being made so far in the future, is a demonstration of an understanding of the detail of what is measured and observed at the site as it is developed. There will be many specific geological features encountered (for example fissures) and it must be shown that these details are consistent with the broad effective properties relied upon and the general principles underlying the safety case. Combinations of parameters that may be encountered and physical couplings between different physical and chemical processes that might occur in the repository, and near repository environment, must be shown not to undermine the integrity of the DSSC.

Conclusions and Recommendations

- **Site characterisation approaches have been extensively developed in research facilities such as underground research laboratories and in actual GDF site characterisation studies in other countries eg, France, Sweden and Finland. These methods should be tested in relevant UK settings to characterise the local geology and a national capability in deep geological site characterisation be expanded**
- **Involvement in European underground research facilities facilitates experience in establishing a detailed understanding of the near-repository environment to be developed. The UK should re-engage in international research programmes to access this experience of working in deep, low-permeability environments.**
- **In order to achieve broad consensus from relevant disciplines, the international nuclear waste community is increasingly using standard tools and techniques for site characterisation and for the DSSC. It is recommended that such tools and techniques are appraised through the academic community and where suitable, tools and techniques used more widely beyond the UK nuclear community are involved in the development of the evidence supporting the DSSC.**

8.2.3 Costs

The NDA's current best estimate within the range of potential costs for a GDF is £12.2bn (2007/8).¹⁷⁶ This cost is not fixed and will, for example, be strongly influenced by changes in the UK waste inventory.¹⁶⁹ Based on the 2007/8 design estimates, which include both the construction cost of the GDF and its operation over its cycle until closure, approximately 25% of the costs are associated with the initial construction.¹⁷⁷ The DECC ambition is that future costs associated with the GDF are funded by the nuclear power station operators. They would then be borne by the consumer in the cost per kWhr of electricity.

The 2011 'Waste Transfer Pricing Methodology', for the disposal of higher activity waste from new nuclear power stations,¹⁷⁸ sets out the key principles underpinning this funding framework:

- The Government's objective is to ensure the safe disposal of intermediate level waste ('ILW') and spent fuel from new nuclear power stations without cost to the taxpayer and to facilitate investment through providing cost certainty. The Government is not seeking to make profits over and above a level consistent with being compensated for the level of risk assumed, but does expect operators to meet their full share of waste disposal costs.
- Prospective new nuclear Operators should be provided with certainty over the maximum Waste Transfer Price they will be expected to pay the Government for the provision of a waste disposal service.
- The Waste Transfer Price should be set at a level over and above expected costs and include a Risk Premium to compensate the taxpayer for taking on the risk of subsequent cost escalation.
- Where possible the Waste Transfer Price should be set in relation to actual cost data, to ensure that any Risk Premium is proportionate and properly reflects the financial risks being assumed by the Government. Therefore, in order to enable greater certainty over expected costs, the setting of the Waste Transfer Price should be deferred for a specified Deferral Period, provided that in certain circumstances it will be possible for the Waste Transfer Price to be set before the end of the Deferral Period.
- During the Deferral Period the Operator must make prudent provision for their waste disposal liabilities, based on an Expected Price provided by the Government.

The cost of waste handling has two components: 1) the cost associated with building the GDF and 2) the cost per tonne of uranium (ie, irradiated fuel) disposed of in the GDF (Unit Disposal Cost or Base Cost). These combined give a cost estimated by DECC of 193£k/tU (thousand pounds per tonne of uranium). In addition, there is a Risk Fee/Premium (to compensate Government for taking on financial risk associated with construction of GDF) which is 60% of the Base Cost, ie, 119 £k/tU. Combined these

give a predicted disposal cost of 312 £k/tU and this is what is called the Waste Transfer Cost/Price. This is a predictive estimate, which provides the operators with a guide price anticipated for disposal. However, given that operation of the GDF is not expected until 2040, the uncertainties associated with the construction may mean that the above estimate will need to be revised upwards. Consequently, the Government has deferred setting the Waste Transfer Price by 30 years from 2020 until 2050. It is likely that the predicted Waste Transfer Price will be reviewed during this period but in order to provide operators with an upper limit that allows them to construct a business model for new build, a Price Cap of 971£k/tU has been set. This is over five times the Base Cost (193 £k/tU). Modelling by the DECC estimates that there is only a 1% probability that the costs will exceed the Price Cap (971£k/tU) over the lifespan of the repository. The DECC calculations are performed at 2008 monetary values and are then indexed by inflation. How does the Price Cap compare with the total cost of the electricity generated by the fuel? Working on the basis that 20 tonnes of fuel are discharged from a typical 1GWe PWR each year, and using current electricity prices, one can easily calculate that the Price Cap represents 1.5–2% of the revenues from the sale of electricity. This probably represents an upper limit, since PWR technology is becoming more efficient (better exploitation of energetic content of the fuel) and electricity prices are likely to rise over time.

The setting of the level of the Price Cap is extremely important, yet delicate. If the Price Cap is too high this discourages operators from investing in new build as the potential financial returns diminish, whereas if it is too low then the additional costs over and above the Price Cap will fall on the Government and the tax payer. These then could be argued to provide an indirect subsidy to the nuclear industry.

8.2.4 Nuclear Inflation

The complexity of construction of large-scale projects is such that a realistic determination of the associated costs is challenging, especially in regard to first of a kind projects. More specifically, the nuclear industry has a poor track record of keeping projects within cost estimates: in recent times the cost of the EDF EPR reactor at Flamenville, France, has seen costs rise at an annual rate of 13% above eurozone inflation¹⁷⁹ and costs of the Darlington reactor in Canada were 70% over budget. The NDA's estimates of the decommissioning costs have risen from £47.9bn in 2002 to £103.9bn in 2011, corresponding to a rate of 4.2–6.0% above inflation.¹⁸⁰

Rates of inflation over and above the base rate will cause the Waste Transfer Price to rise and could, in principle, exceed the Price Cap. It is estimated¹⁸¹ that, with a 4.5% level of nuclear inflation, the Price Cap would be exceeded in 2047, resulting in a £130m Government subsidy¹⁷⁷. The proposed new build reactors have an operational lifetime of 60 years (as opposed to the 40 years of existing reactors that were used for the above estimate). This would increase the required government subsidy to £1.13bn per reactor.

In the past, models to streamline costs and reduce delays within the nuclear sector have been shown to work in France and Japan, where the licensing of reactors was not performed piecemeal but rather on a single reactor design, which was then reproduced in construction – a model not used previously in the UK.¹⁸² In addition, it is noted that savings can be made through the construction of 'several-of-a-kind' reactors: DECC estimates are based around a conservative estimate of ten new build reactors. However, such effects are not relevant for a GDF, which will always be a 'one-off' facility constructed in a particular host rock environment and responding to local conditions, and cost savings will only be possible though, for example, ensuring clear regulatory guidelines, ideally based on international best practice so that experience from other projects abroad is also relevant.

Recommendations

- **The model of the Generic Design Assessment (GDA) applied to the review of future PWR reactors by the Environment Agency and Office of Nuclear Regulation (ONR) should be applied to the Geological Disposal Facility (GDF) in order to minimise changes in design during construction and the associated cost escalation. In this line, the current work of the Environment Agency and Office of Nuclear Regulation is an appropriate approach.**¹⁸³
- **GDF construction and design should be strongly informed by existing projects such as those ongoing in Europe. In this regard scientific and regulatory collaboration should be further developed.**
- **The DECC should consider whether the possible risk of nuclear inflation is an appropriate quid-pro-quo for the risk of sharing in the construction of the GDF.**

8.2.5 Spent Fuel Disposal

It is currently expected that spent fuel from new nuclear plants will not be reprocessed but instead disposed of directly as waste (see, however, the discussion about MOX and Gen-IV reactors in Chapter 4). One of the key elements of the calculation of the Base Cost (193 £k/tU) relates to the packing density of the spent fuel elements, or bundles, within the disposal canisters – shown in Figure 11. Apart from the so far insufficiently addressed issues of deterioration in storage and potential corrosion problems, the DECC costing is based on spent fuel from new build PWRs, whereas the fuel in the UK's existing reactor fleet of AGRs is much less compact (ie, more space between the individual fuel pins in the bundles) meaning that disposal will be more expensive¹⁷⁷. It is estimated that the combined

¹⁷⁶ Nuclear Decommissioning Authority (NDA) (2008): 'Annual Report and Accounts 2007/8' The Stationery Office: London. <http://www.nda.gov.uk/documents/upload/Annual-Report-and-Accounts-2007-2008.pdf>

¹⁷⁷ Jackson, I. (2011): 'Research Report – Subsidy Assessment of Waste Transfer Pricing for Disposal of Spent Fuel from New Nuclear Power Stations. Independent Report for Greenpeace UK' Issue 1. Jackson Consulting: Cheshire <http://www.greenpeace.org.uk/sites/files/gpuk/FUP-Subsidy-Report-Mar2011.pdf>

¹⁷⁸ Department for Energy and Climate Change (December 2011): 'Waste Transfer Pricing Methodology for the disposal of higher activity waste from new nuclear power stations' DECC: London <http://www.decc.gov.uk/assets/decc/consultations/nuclear-waste-transfer-pricing/3798-waste-transfer-pricing-methodology.pdf>

cost of disposal of spent fuel from existing and future reactors could as a result be 2.5 times higher than the DECC estimate of the base cost. The 2011 NDA review¹⁷³ indicated that more efficient packing of the AGR fuel rods was being considered, which would reduce the estimated cost to double the DECC estimate.¹⁸¹ However, it is clear that the DECC estimate does not account for the costs linked to the disposal of fuels from the existing nuclear power station fleet. Such factors reduce the margin of error in the DECC estimate of 99% probability that the Price Cap will not be exceeded.

Conclusions and Recommendations

- **A method is required for determining the Waste Disposal Base Price that accounts for different fuel types. This should account for current and future generation power stations. The three different Base Costs for disposal of PWR, AGR or MOX spent fuels should be published to assist public understanding and market transparency.**
- **The costs associated with reprocessing wastes and legacy high level waste need to be clearly defined and the responsibility for these costs, and any uncertainty associated with the legacy waste inventory, assigned.**

¹⁷⁹ Source: EDF Investor Statements (2005–2011) <http://shareholders-and-investors.edf.com/news-and-publications/annual-reports-42724.html>

¹⁸⁰ Source: DTI and NDA (2002–2011) <http://www.greenpeace.org.uk/sites/files/gpuk/FUP-Subsidy-Report-Mar2011.pdf>

¹⁸¹ Using the FUPSIM model – <http://www.jacksonconsult.com/fupsim.html> (Jackson 1); <http://www.greenpeace.org.uk/sites/files/gpuk/FUP-Subsidy-Report-Mar2011.pdf>

¹⁸² Evidence given in Policy Commission Workshop One (15 December 2011)

¹⁸³ Environment Agency: Regulating Geological Disposal <http://www.environment-agency.gov.uk/business/sectors/111766.aspx>



Public perception and opinion

Whilst science and technology are key inputs in formulating policy on the future of nuclear energy and dealing with radioactive waste, this policy cannot be successful if it neither understands public perceptions and concerns nor deals with them in a just and equitable manner.

9.1 Background

To this end it is vital that (social science) research is utilised effectively to enable policy makers, industry and other stakeholders to understand the trends, influences and resilience of opinion amongst the general public and local communities. Understanding public opinion is central to any potential transition to a low carbon future because beliefs and perceptions influence which types of energy systems, including nuclear power, people will be willing to accept. Given this importance, there have been numerous examinations of trends in public opinion towards nuclear energy both nationally and internationally^{184, 185, 186, 187, 188, 189, 190}.

Research demonstrates that the public 'do not like projects that pose highly uncertain risks, unless they see great compensating benefits and have deep trust in the institutions managing them'.¹⁹¹ The discourse around decision making in the public arena has shifted from a focus on a predominantly top-down process characterised as 'decide announce defend' (DAD) within an inherent culture of secrecy, to a more collaborative process in which industry and government actively engage with the public and their concerns. Historically, a lack of openness on the part of the nuclear industry and the regulatory agencies can be seen to have blighted the image of the nuclear industry, leading to increasing calls for greater openness and engagement with the public. This has required a cultural shift within the nuclear industry, as well as government itself,

characterised by some as 'learning to listen'.¹⁹² Early engagement with the public is seen to be the key to achieving community buy-in and ensuring legitimacy of outcomes. Various research studies have reported on the successes of public participation.¹⁹³

Drivers of public opinion include safety concerns (particularly after events such as Fukushima), the association with nuclear weapons, concerns around waste disposal, proliferation concerns, the invisible and long term nature of radiation, the involuntariness of exposure, and the level of trust placed in institutions that manage and regulate nuclear sites. Over the last few decades the nuclear industry has increasingly attempted to employ transparency and openness in part in response to these public concerns.

¹⁸⁴ Nuclear Energy Institute (September 2011): 'Latest Trends in U.S. Public Opinion About Nuclear Energy' <http://www.nei.org/resourcesandstats/documentlibrary/reliableandaffordableenergy/reports/latest-trends-in-us-public-opinion-about-nuclear-energy-sept-2011>

¹⁸⁵ The Parliamentary Office of Science and Technology (October 2007): 'Postnote: Public Opinion on Electricity Options' POST: London <http://www.parliament.uk/documents/post/postpn294.pdf>

¹⁸⁶ Barasi, L. (August 2011): 'Energy Sources: How worried are we really getting about energy security?' <http://www.noiseofthecrowd.com/category/energy-sources/>

¹⁸⁷ Ipsos MORI (November 2010): 'Public Attitudes to the Nuclear Industry' <http://www.ipsos-mori.com/researchpublications/researcharchive/2707/Nuclear-power-the-highest-public-support-in-over-a-decade.aspx>

¹⁸⁸ Black, R. (2011): 'Nuclear power 'gets little public support worldwide' BBC News, 25 November 2011 <http://www.bbc.co.uk/news/science-environment-15864806>

¹⁸⁹ British Science Association (August 2011): 'Nuclear Fallout?' Analysis prepared by Populus <http://www.britishsociety.org/web/News/FestivalNews/nuclearpoll.htm>

¹⁹⁰ Nuclear Energy Agency (NEA), Organisation for Economic Co-operation and Development (2010): 'Public Attitudes to Nuclear Power' OECD: Paris <http://www.oecd-nea.org/ndd/reports/2010/nea6859-public-attitudes.pdf>

¹⁹¹ Rosa E.A., Tuler S.P., Fischhof B., Webler T., Friedman S.M., Sclove R.E., Shrader-Frechette K., English M.R., Kasperson R.E., Goble R.L., Leschine T.M., Freudenburg W., Chess C., Perrow C., Erikson K. and Short J.F. (2010) 'Nuclear Waste: Knowledge Waste?' *Science* Vol 329, no. 5993 pp. 762–763

¹⁹² Mackerron G and Berkhout F (2009): 'Learning to Listen: Institutional Change and Legitimation in UK Radioactive Waste Policy' *Journal of Risk Research* Vol. 12, Nos. 7–8, October–December 2009, 989–1008 http://www.ivm.vu.nl/en/Images/UKradioactivewaste%2009-04_tcm53-105564.pdf

¹⁹³ Abels G (2007): 'Citizen Involvement in Public Policy-making: Does it Improve Democratic Legitimacy and Accountability? The Case of pTA' *Interdisciplinary Information Sciences*, Vol. 13, No. 1, pp. 103–116 (2007) and Beierle T.C. (2002): 'The quality of stakeholder-based decisions' *Risk Analysis* 22, pp. 739–749

9.2 Public Opinion Leading Up to Fukushima

As illustrated in Figure 12 below, the last one and a half decades prior to the Fukushima incident (2011) had seen, on average, a rise in the international approval rating of nuclear energy.¹⁹⁴ Many have referred to this as the 'nuclear renaissance', said to have been characterised by a moving away from a public perception of nuclear as a uniquely distrusted, stigmatised industry – a perception that was particularly strong following on from the Chernobyl incident. Over time, nuclear can be seen to have gradually become one among many other risks associated with energy generation, with a general public awareness that it had a contribution to make in off-setting climate change, for example.¹⁹⁵

Factors such as national politics and relationships with the domestic nuclear industry are influential in national public support for nuclear energy¹⁹⁴. For the European Union member states, with one or two exceptions, there is a strong correlation between a country operating nuclear power stations and being more positive (or less negative) towards nuclear energy¹⁹⁶ in a range of issues. Nordic member states and those operating nuclear power stations in Central and Eastern Europe show the most positive attitudes (certainly in recent years), and this can probably be explained by a number of arguments relating to the successful outreach by the nuclear sector in Sweden and Finland, and to national pride in home-grown heavy industry and large-scale construction projects in the case of Hungary, the Czech Republic and Slovakia.

There is little correlation between the outright level of support and the percentage of electricity produced by nuclear energy – eg, France, though having the highest percentage of any country in the world, shows only moderate levels of public support.

Recent trends in UK opinion (Figure 13) demonstrate a steadily increasing public approval rating of nuclear energy since the early 2000s. The marked increase in opposition to nuclear energy just prior to that coincided with a period in which the reputation of the nuclear industry was under question as, for example, the Nuclear Installations Inspectorate confirmed that safety records relating to a shipment of uranium and plutonium mixed oxide fuel to Japan had been faked at BNFL's Sellafield facility in Cumbria (2000). Moreover,

Figure 12: Trends in the Approval Rating of Nuclear Power Between 1994 and 2009 ^{Ref 190}

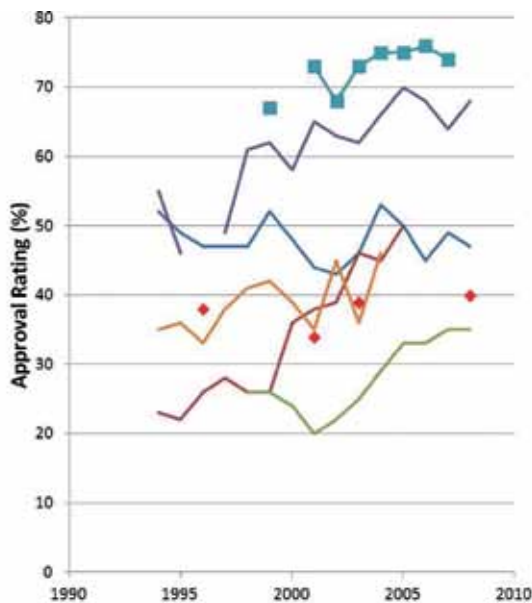
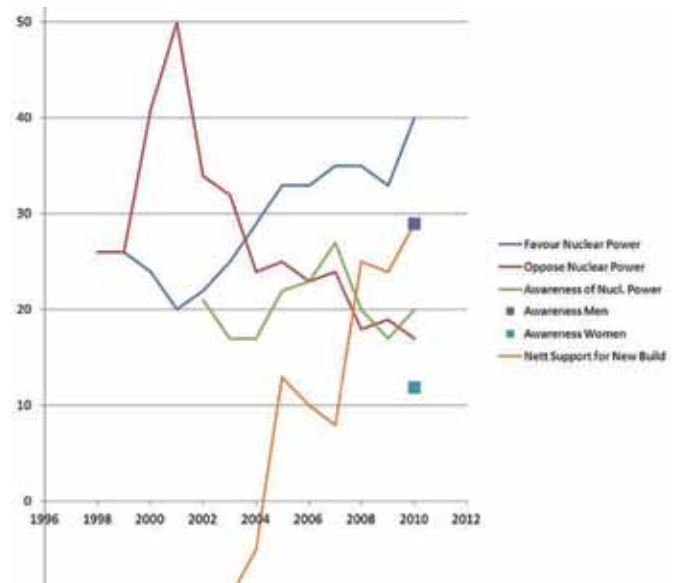


Figure 13: Levels of Support For and Opposition To Nuclear Power in the UK Between 1998 and 2010. Also shown is the net level of support for new build and the level of awareness of the nuclear industry – with the two points showing the split between men and women.¹⁸⁷



¹⁹⁴ Ratio of in favour to against, % of electricity from nuclear power was; USA (1.9, 19.6%), UK (1.3, 15.7%), Sweden (1.5, 38.1%), France (1.2, 74.1%), Finland (1.8, 28.4%), Hungary (3.2, 42.1%) and Japan (1.1, 29.2%)

¹⁹⁵ Evidence given in Policy Commission Workshop One (15 December 2011)

¹⁹⁶ Nuclear Energy Agency (NEA), Organisation for Economic Co-operation and Development (2010): 'Public Attitudes to Nuclear Power' OECD: Paris <http://www.oecd-nea.org/ndd/reports/2010/nea6859-public-attitudes.pdf> which is based heavily on Eurobarometer surveys carried out for the European Commission on nuclear-related issues http://ec.europa.eu/public_opinion/index_en.htm

in July 2002, BNFL reported a £2.3bn loss, the worst result in the company's history. Also during this period, the attack on the World Trade Center in New York heightened concerns over terrorist attacks on nuclear installations. Consequently, there is clear public sensitivity to the reputation of the industry and the perceived level of safety, which can have a sustained impact on opinion.

In an era in which there is a potential new build programme there is increased focus and research around the area of public confidence and opinion in nuclear energy. A 2010 poll by the Understanding Risk Research Group (Cardiff University)¹⁹⁷ found that only 39% of people believed that the nuclear industry could be trusted to run nuclear power stations safely. A series of public engagement processes

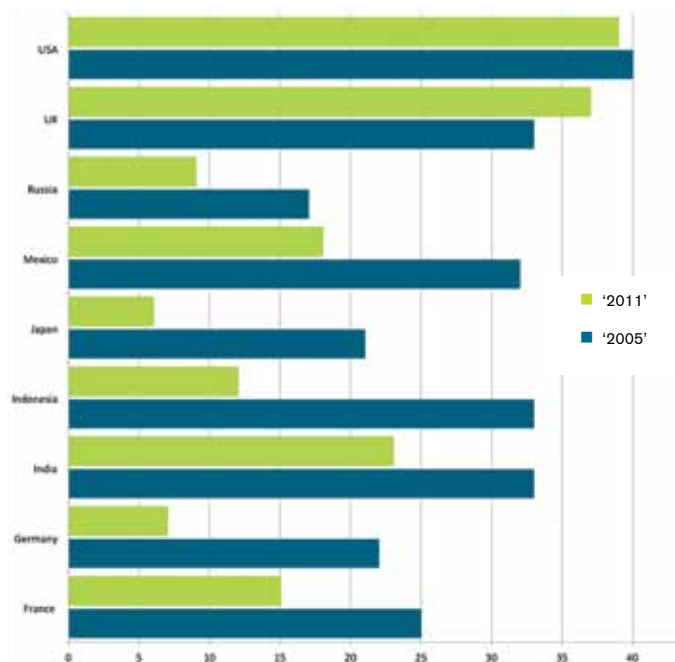
conducted for the DTI (2002) suggested that 'in all processes there were strong views for (eg, it is a low carbon option) and against (eg, safety concerns) and a large body of concerned but undecided opinion'.¹⁹⁸ This again reveals the sensitivity of public opinion to both nuclear safety record and the degree of trust and confidence the public have in the nuclear industry.

Qualitative social science research has been instrumental in helping to probe below the surface of responses to surveys in order to ascertain how individuals come to make sense of nuclear energy and the nuances and tensions that underpin stated views. Several studies have demonstrated the existence of a 'reluctant acceptance' of nuclear energy, reflecting the complex ways in which

participants re-negotiated their position on nuclear energy in light of concerns over climate change^{199, 200}. Such findings are reinforced by data from recent national surveys which suggest support for nuclear as fragile at best.²⁰¹ During focus group discussions, shifts were observed towards more mixed and open views about nuclear energy, from initial negative views, when considering climate change. Pursuing the nuclear option was seen as the lesser of two evils, a choice of last resort in the face of the threat of climate change, reflecting 'a resignation verging on frustration that there was no avoiding some continued dependence on the nuclear sector'¹⁹⁹. Qualitative research has demonstrated the existence of a significant 'concerned but undecided opinion' on nuclear energy, which often reflects 'a reluctance to accept [nuclear energy] except under very stringent conditions'.²⁰² This perceived absence of meaningful choice in the light of the need to mitigate climate change may be a contributing factor to the rebound in public opinion after Fukushima (see below).

Between the extremes of strong support and strong opposition to nuclear energy, public attitudes towards nuclear energy are not fixed, and have evolved over the last decade through a process of negotiation around the re-framing of nuclear energy as a solution to a range of climate and energy challenges. The apparent volte-face by prominent environmentalists such as James Lovelock, George Monbiot and Mark Lynas to supporting new nuclear build can be seen to have contributed to this changed public discourse.²⁰³

Figure 14: Changes in the Level of Support (in percent) for Nuclear Power Pre- and Post Fukushima^{Ref 188}



¹⁹⁷ Spence, A., Venables, D., Pidgeon, N., Poortinga, W. and Demski, C. (2010): 'Public Perceptions of Climate Change and Energy Futures in Britain: Summary Findings of a Survey Conducted in January-March 2010. Technical Report' Understanding Risk Working Paper 10-01. Cardiff University: School of Psychology. <http://www.understanding-risk.org/>

¹⁹⁸ DTI (September 2002): 'Integrated Public and Stakeholder Consultation to inform the Energy White Paper: Summary report' A process designed and managed by IPPR, UK CEED, New Economics Foundation and Dialogue by Design on behalf of the DTI p 10

¹⁹⁹ Bickerstaff K., Lorenzoni I., Pidgeon, N.F., Poortinga W., Simmons P., (2008): 'Reframing nuclear power in the UK energy debate: nuclear power, climate change mitigation, and radioactive waste' Public Understanding of Science 17, 145-169.

²⁰⁰ Venables D., Pidgeon N., Simmons P., Henwood K., & Parkhill K. (2009). 'Living with nuclear risk: A Q-method study.' *Risk Analysis*, 29(8), 1089-1104.

²⁰¹ Corner A., Venables D., Spence A., Poortinga W., Demski C., and Pidgeon N. F., (2011): 'Nuclear Power, Climate Change and Energy Security: Exploring British Public Attitudes' Energy Policy 39: 9, 4823-4833

²⁰² A process designed and managed by IPPR, UK CEED, New Economics Foundation and Dialogue by Design on behalf of the DTI (September 2002): 'Integrated Public and Stakeholder Consultation to inform the Energy White Paper. Summary report' http://webarchive.nationalarchives.gov.uk/+http://www.dti.gov.uk/energy/developpe/int_public_and_stake_con_rep.pdf p 22

²⁰³ The National (Nov 21, 2008): 'Activists give environmental movement a nuclear shock' <http://www.thenational.ae/news/uae-news/environment/activists-give-environmental-movement-a-nuclear-shock>

9.3 Public Opinion Post Fukushima

The immediate aftermath of the Fukushima disaster witnessed dramatic shifts in public opinion, with a surprising move in the UK towards nuclear energy¹⁸⁸. More broadly, in countries with existing nuclear energy, opposition increased¹⁸⁸. Only 22% of those polled in 23 countries by GlobeScan (2011) agreed with the statement that 'nuclear power is relatively safe and an important source of electricity and we should build more nuclear power plants';¹⁸⁸ 39% supported continuing with existing reactors without building new ones; and 30% desired an immediate shutdown¹⁸⁸. Specifically in France, a poll carried out for the *Journal du Dimanche* found that 77% of those questioned wished nuclear energy to be either phased out or stopped immediately.²⁰⁴ Such public reaction has been a factor in the decision by several governments to dramatically change their energy policies. Most notable was the decision in Germany to take seven older reactors offline immediately and to phase out the remaining nine by 2022. In Switzerland, where nuclear power accounts for 40% of electricity generation, the Federal Council decided in May 2011 on a slow phase-out – not extending operation times or building new power plants; the first power plant will stop running in 2019, the last in 2034. As of November 2011, 80% of Japan's 54 nuclear power stations were offline (nuclear power represents 29.2% of electricity generation in Japan) as controlled by the local prefectures.²⁰⁵ The future in Japan is unclear. More widely, the loss of public confidence is expected to contribute to a slowing down of international new build plans.

Remarkably, the impact of Fukushima on public opinion and government policy in the US and UK appears to have been more marginal, with even a small increase in support for nuclear energy and new build in the UK¹⁸⁹. In 2010,

just prior to Fukushima, net support for new build in the UK stood at approximately 30%¹⁸⁷ (Figure 13). In the immediate aftermath of Fukushima the 'reluctant acceptors', withdrew their support for nuclear energy and, in particular, for nuclear new build.²⁰⁶ There has, however, been a remarkable bounceback in public support for replacing existing nuclear power stations in the UK since Fukushima with support now increasing. A similar situation was observed after the Three Mile Island (TMI) incident in the US in 1979 which saw a temporary increase in opposition to nuclear energy as a result of the media coverage 'but when the media spotlight was turned off, public opinion rebounded almost immediately to pre-TMI levels'.²⁰⁷ This process has been labelled the 'rebound' hypothesis.²⁰⁸

The media reporting of both climate change and nuclear energy have been central in fostering its acceptance, however reluctantly, in the UK. Whilst recognising the media do not in any simplistic sense 'tell people what to think', they nonetheless play a key role in articulating both pre-existing and novel ideas, or *frames*, through which people make sense of and form opinions about nuclear energy. Within the media a number of overlapping frames compete for attention, eg, those that emphasise progress, energy independence, and recently climate change. Nuclear energy has been increasingly analyzed in the media in relation to a climate change narrative in the same way that different frames were used in previous decades – from a progress frame up to the 1970s to a *runaway technology* frame after TMI and Chernobyl²⁰⁷. Public concern over climate change may not be due only to accurate reporting of climate science but may also reflect concern generated (by the media), emphasising fear and doom.²⁰⁹ It is also clear that having a strong independent regulator with integrity is extremely important in building confidence. In this sense the role of Mike Weightman²¹⁰ has been extremely important.

9.4 What Are the Issues?

A 2010 Ipsos MORI poll¹⁸⁷ shows 70% agreement (with 9% strongly against) for the thinking that 'Britain needs a mix of energy sources to ensure a reliable supply of electricity, including nuclear power and renewable energy sources'. Support for new nuclear build in the UK was found to be 68% if proposals for the new build programme are coupled with a concerted policy of promoting renewables.²¹¹ A 2010 YouGov/EDF survey²¹² also showed, however, that **there is only a passing awareness of energy as a significant challenge facing Britain, and that when it comes to energy, more people are interested in national self sufficiency rather than issues associated with climate change.**

The main concerns of people when it comes to nuclear energy are risk, waste disposal and concerns over radiation¹⁹⁰. It is, however, noted that the number of people who profess an awareness of nuclear energy¹⁸⁷ (Figure 13) has remained fixed over the last decade at a relatively low level of 20%. Further broken down according to gender, only 12% of women claim to have an understanding of the nuclear industry, against 29% of men. A similar divide exists in relation to support for new build with 34% of women supportive (23% against) and 61% of men supportive (13% against)¹⁸⁷. Similar conclusions were reached in a poll released by the British Science Association¹⁸⁹. Other studies show that the bounceback in support of nuclear energy after Fukushima has been stronger among men than women²¹³. This reinforces previous research which suggests that men are on average more supportive of nuclear energy than women¹⁹⁷. There is also a bias when it comes to age and social class^{187, 189, 213} with only 32% of 16–24 year olds being supportive of new build compared to 60% for those aged 55–60, and support for new build among social class DE (working class) at 38% compared to 68%

²⁰⁴ Le Figaro (June 2011): 'Anti-nuclear opinion is increasing in France' <http://plus.lefigaro.fr/note/anti-nuclear-opinion-is-increasing-in-france-20110606-477470>

²⁰⁵ Simplyinfo – the Fukushima Project (November 2011): '80% of Japan Nuclear Power Plants Now shut Down' <http://www.simplyinfo.org/?p=4178>, and see the Reuters link <http://www.reuters.com/article/2011/11/24/nuclear-japan-status-idUSL3E7L708120111124>

²⁰⁶ Butler C., Parkhill K. A. and Pidgeon N.F. (2011) 'Nuclear Power After Japan: The Social Dimensions' Environment November-December 2011 <http://www.environmentmagazine.org/Archives/Back%20Issues/2011/November-December%202011/Nuclear-full.html>

²⁰⁷ Gamson W.S. and Modigliani A. (1989): 'Media Discourse and Public Opinion on Nuclear Power: A Constructionist Approach' American Journal of Sociology, Vol. 95, No. 1 pp. 1–37: p 34

²⁰⁸ de Boer C., and Catsburg I. (1988): 'The Polls: The Impact of Nuclear Accidents on Attitudes toward Nuclear Energy' Public Opinion Quarterly 52:2: 254–61 and Freudenburg W.R., and Rosa E. A. (1984): 'Are the Masses Critical?' in Freudenburg W.R. and Rosa E.A. (eds): Public Reactions to Nuclear Power: Are There Critical Masses? pp. 331–48. Boulder, CO: Westview/American Association for the Advancement of Science.

²⁰⁹ Boykoff, M.T. (2008): 'The cultural politics of climate change discourse in UK tabloids'. Political Geography 27 (5): 549–569. doi:10.1016/j.polgeo.2008.05.002.

²¹⁰ Office for Nuclear Regulation. An agency of HSE: 'Mike Weightman on events in Japan' <http://www.hse.gov.uk/nuclear/news/2011/mar-japan.htm>

²¹¹ YOUGOV (2006): Poll for the Economist 'Nuclear Energy' <http://ukpollingreport.co.uk/blog/archives/273>

²¹² YouGov (2010): 'YouGov / EDF Energy Survey Results' http://cdn.yougov.com/today_uk_import/YG-Archives-Pol-EDF-energy-130510.pdf

²¹³ Pampel F. C. (2011): 'Support for Nuclear Energy in the Context of Climate Change: Evidence from the European Union' Organization & Environment 24(3) 249–268

among social class AB (upper-middle class). Similar trends have been identified in international studies, showing a correlation between support for nuclear and level of educational attainment, and higher support associated with increasing age.²¹³ Studies have also shown an association between higher support and right-of-centre political beliefs.

However, not all of these findings are consistent across different research projects – for example the correlation between age and support. Furthermore, there can be far more complex issues at play including the way that the positions we take up as knowers ('epistemic subjects') are also grounded in our values and ethical sensibilities. These are personally and socially meaningful, and hence may be very influential in how we relate to matters of public concern. In the case of gender it is well known that diverse values around care, relationships, environmental protection and futures need to be taken seriously. So the framing of the 'knowledge of nuclear' issue needs to take into account the possible neglect of these issues in the formation of policy.²¹⁴

A range of variables are important in the relationship between the public and an understanding of the nuclear industry, eg, income, gender, political ideology, cultural values and trust in the information source. Consequently, it cannot automatically be presumed that more information will lead to greater acceptance^{215, 216}.

It is clear that the majority of people sampled in polls have only a passing understanding of the nuclear industry, how electricity is generated in reactors, whether it is possible to safely dispose of nuclear waste, the hazards or otherwise of radiation, climate change issues and the concerns surrounding energy security. Women are more likely to answer 'don't know' and a lack of support in young people may also reflect a lower level of understanding.

A greater emphasis on developing an awareness of energy in schools and opening up the nuclear debate could help with engagement in the nuclear industry and energy generation. However, a better understanding of the diverse values around care, relationships, environmental protection and futures needs to be taken seriously.

At the same time, effective communication has been shown to be hampered by a lack of trust in the nuclear industry and government, leading to calls for greater two way communication and greater deployment of effective citizen engagement initiatives such as those pioneered by Committee on Radioactive Waste Management (CoRWM). **Citizen engagement initiatives need to be informed by such careful qualitative, interpretive and analytical work.**²¹⁷

A 2010 OECD¹⁹⁰ report makes a number of recommendations, two of which are especially pertinent here:

'If governments wish to expand the use of nuclear energy, an ongoing relationship between policy makers, the nuclear industry and society that develops knowledge building and public involvement will become increasingly important. This communication must be open, honest and balanced.' and 'The public gains most of its information on energy and nuclear power from the media, but does not trust it. Scientists and environmental protection or consumer organisations are the most trusted groups. National governments are, in general even less trusted on these issues than the media. This presents a clear problem to governments who wish to educate and influence their publics.'

It is manifestly clear that there remain significant challenges in developing informed public opinion and debate in the UK. The benefits of nuclear energy need to be discussed together with the risks and challenges in order to foster trust.

Conclusions and Recommendations

- A strong, transparent, independent nuclear regulator, situated outside Government but with regulatory powers, is essential for building public trust in the nuclear industry and fission technology. The recently constituted Office for Nuclear Regulation (ONR)²¹⁸ fulfils this role. Continued high levels of safety and demonstrable independence are crucial in enhancing domestic confidence.
- Genuine and open public discussions of the pros and cons of nuclear energy with inclusion of stakeholders from across the spectrum of opinion are vital.
- A proactive approach by the NDA to explaining the science behind geological waste disposal and its robustness, recognising and communicating the scientific uncertainties and technological challenges is necessary.
- An independent panel of UK experts drawn from academia and national organisations such as NNL and NDA should be established to provide informed, independent, advice to the media, Government and public. Public understanding of the risk and impact of nuclear energy and radiation are a priority.
- Recognise the need for an inclusive democratic participative process where alternative narratives of the issues can emerge that are not constrained by narrow technocratic, science-based arguments.
- Stimulation of public debate on energy security, the energy mix and the role of nuclear energy. This is timely given the need to reshape the UK energy landscape. The broadening of the debate across the genders is crucial, as is the education of young people in energy issues.

²¹⁴ K.L. Henwood, K.A. Parkhill and N.F. Pidgeon, *EOI*, 27 (2008) 662.

²¹⁵ House of Lords Report (2000): 'Science and Society' Her Majesty's Stationary Office: London

²¹⁶ Written evidence submitted by Nick Pidgeon to the House of Commons Science and Technology committee 'Risk perception and energy infrastructure' session <http://www.publications.parliament.uk/pa/cm201012/cmselect/cmsctech/writev/risk/m21.htm>

²¹⁷ Parkhill K. A., Henwood K. L., Pidgeon N. F. and Simmons P. (2011): 'Laughing it off? Humour, affect and emotion work in communities living with nuclear risk', *British Journal of Sociology*, 62(2), 324–346

²¹⁸ Office for Nuclear Regulation. An agency of HSE <http://www.hse.gov.uk/nuclear/ndchanges.htm>

9.5 Living with Nuclear Power

Evidence exists suggesting that people living close to nuclear power stations are generally more supportive of the industry than those living further afield^{219, 220}. Research conducted 25 years ago illustrated that those living close to a nuclear plant tend to discount risks, particularly if they gain economically from it. They are also more likely to support the building of a new plant and less pessimistic about the immediate impact of construction (excavation, influx of people etc) than those who do not live near an existing plant. Although this research was carried out in the 1980s it indicates that familiarity and benefit thus play an important role in public perception. Research also highlights people's awareness of the challenges and negative aspects of living so close to a station, for example the recognition that construction could negatively affect peace of mind (creating stress and anxiety), and concern over transport of nuclear waste.²²¹ When asked, 77% of local residents at Oldbury and Bradwell expressed concern over nuclear waste²¹⁸.

A 2010 poll prepared for EDF by ICM Research²²² sampled 'Public Attitudes Towards Hinkley Point Power Station', asking local residents (those within 25 miles of the power station): 'Overall, do you think a new power station will have a positive or a negative impact on the local area?'. This produced a net positive answer of 27% (59% believing there to be a positive impact, 32% a negative impact). In contrast, the Public Perceptions of Climate Change and Energy Futures in Britain¹⁹⁷ survey found that 60% of those polled were opposed to a new nuclear power station (or coal station) being built within five miles of where they lived, with 39% strongly

opposed to the construction of a nuclear power station. This contrasts markedly with the 73% who would tolerate the construction of a wind-farm within the same radius. There remains a broader lack of confidence in nuclear energy over other energy technologies.

The main reason given by those local to Hinkley Point for supporting a new nuclear power station was the boost it would bring to the local economy (81%). The main negatives were seen to be the environmental damage that building a power station would bring (33%) followed by safety concerns (32%) and traffic congestion from construction (15%)²²².

Local communities often see nuclear power stations as crucial employers in remote, peripheral communities, particularly in the absence of any other major employer.²²³ The value placed on stations is demonstrated in the local response to the Government's refusal to issue EDF Dungeness with a licence to develop two new nuclear power stations at the site (July 2011). This caused local dismay,²²⁴ resulting in a petition in favour of a new power station being delivered to Downing Street on behalf of the inhabitants of Romney Marsh. From a public opinion perspective, the policy of locating new build sites close to existing nuclear power plants taps into the positivity of local communities. However, there are inherent risks in the nuclear industry taking host communities for granted, and not engaging in a consensual way, and these can still generate hostility as has been documented in the case of the RWE engagement with communities in Cumbria.²²⁵

Qualitative research suggests a complex picture and the need to look beyond the headline statistics of the relationship between

geographic proximity and attitudes to nuclear²¹⁸. People who live near to or who are familiar with a nuclear site perceive greater benefits and fewer risks.²²⁶ Geographic proximity to a nuclear site can desensitize residents to the risks.²⁰⁷ Indeed research has demonstrated how people cope with and adapt to such geographic proximity, developing a suite of coping mechanisms. It appears that familiarity with the power plant gained through an individual's social networks connects them to the power plant, which can act to demystify the station as distant and threatening (which can also function to increase trust).

When siting new plants, promoters must reassure the local public about potential or perceived environmental harms;²²⁷ information must be deployed by 'honest brokers' as part of a dialogue with local publics and local government. Local people need to feel they are involved and in control of the process and are not having it forced on them.

Conclusions and Recommendations

- **The communities who live with nuclear power need to be given a national voice as they live more directly with the risks. This could be facilitated by providing funding so that they can perform independent research (as done in France). Learning from successful overseas models is crucial.**
- **Operators need to sensitively engage existing local community organisations to develop trust²²⁵.**

²¹⁹ Parkhill K.A., Henwood K.L., Pidgeon N.F., Simmons P. and Venables D. (2010) 'From the familiar to the extraordinary: the ebbs and flows of local residents' perceptions of risk when living with nuclear power in the UK' *Transactions of the Institute of British Geographers* 35 (1) 39–58

²²⁰ Evidence given in Policy Commission Workshop One (15 December 2011)

²²¹ Van Der Pligt J., Eiser R. and Spears R. (1986) 'Attitudes toward Nuclear Energy: Familiarity and Salience' *Environment and Behavior* 18 (1): 75–93 <http://dare.uva.nl/document/5579>

²²² ICM poll for EDF Energy (2010): 'Public Attitudes towards Hinkley Point Power Station' http://www.icmresearch.com/pdfs/2010_oct_hinkley_survey.pdf

²²³ Blowers, A. & Leroy, P. (1994) 'Power, politics and environmental inequality: a theoretical and empirical analysis of "peripheralisation"' *Environmental Politics*, 3 (2) p. 197–228

²²⁴ Blair D. (2011) 'Dungeness Residents Embrace Nuclear Power' *Financial Times* 07 August 2011 <http://www.ft.com/cms/s/0/834f2600-be7a-11e0-ab21-00144feabdc0.html#axzz1iOlikSq>

²²⁵ Haraldson S., Wylie R. and Howe J. M. (2011): 'When nuclear is normal' *Nuclear Future*, 7(6), 44

²²⁶ Greenberg M (2009), 'NIMBY, CLAMP and the Location of New Nuclear-Related Facilities: U.S. National and Eleven Site-Specific Surveys, Risk Analysis', *An International Journal*, 29(9), 1242–1254, 2009 and Van Der Pligt J., Eiser R. and Spears R. (1986) 'Attitudes toward Nuclear Energy: Familiarity and Salience' *Environment and Behavior* 18 (1): 75–93 <http://dare.uva.nl/document/5579>

²²⁷ Greenberg M. (2009): 'What environmental issues do people who live near nuclear facilities worry about? Analysis of national and site specific data' *Environmental Planning and Management*, 52(7), 919–937

9.6 Sites for Geological Disposal

A series of bitter conflicts over the siting of nuclear power plants (Sizewell B, Hinkley Point C), reprocessing facilities (THORP) and the proposed Rock Characterisation Facility (RCF) at Sellafield have emerged since the 1970s, bolstered by the growth of anti-nuclear movements.²²⁸ Failures of the hitherto used 'decide announce defend' (DAD) approach to identifying sites for radioactive waste and nuclear power stations resulted in a move towards a more open inclusive approach. In 2002 Nirex²²⁹ (established in 1982 by the nuclear industry to examine geological disposal) stated that, 'In the UK today there is enough radioactive waste to cover a football pitch to a height of about ten metres. Most of this waste is produced by the nuclear power industry. Some of the waste will remain hazardous for thousands of years. There is a need, therefore, for a long-term strategy to manage this waste. ...For many people, the scale of the problem was a strong argument for stopping nuclear energy immediately. Given that no agreement had yet been reached on what to do with the existing waste, it was considered irresponsible and immoral to continue producing anymore.' Finding a solution for managing waste falls to the Nuclear Decommissioning Authority (NDA) through the Radioactive Waste Management Directorate and is a high national priority.

In the 1980s Nirex developed proposals for siting low-level nuclear waste repositories at Billingham, Elstow, Bradwell, Fulbeck, and South Killingholme but these were subsequently abandoned due to local opposition. The failure was mainly in local engagement and communication with, for

example, site selection being announced through the media rather than community engagement. The process for selecting a disposal site has since restarted using a more sensitive approach. The challenges today include articulating the scientific case (earlier rebuffed by Friends of the Earth²³⁰), locating an appropriate geological site, and finding a willing host community. There will likely need to be some compromise between the latter two. It is noted that members of the public express great concern about the possible siting of a nuclear waste repository in their locality even if they support nuclear energy in the abstract.²³¹

The failure of the 1997 RCF planning inquiry at Sellafield forced the nuclear industry to rethink its strategy for finding a site for the long term disposal of nuclear waste. The search for legitimacy led to the creation of the Committee on Radioactive Waste Management (CoRWM) in 2003 which initiated one of the most thorough processes of public and stakeholder engagement seen in the UK to date. This attempt to institute a process of adaptive learning and trust building, the emphasis placed on the transparent use of public inputs, has become best practice internationally.²³²

In a change of approach, following the Government White Paper on a Framework for Implementing Geological Disposal (published on 12 June 2008¹⁷⁰), an open invitation was issued to all communities in England and Wales to express their 'without commitment' interest in discussing participation in a deep geological disposal facility (GDF) siting programme. The attractions to communities of hosting a GDF were shown to include employment, but also long-term

socio economic investments in addition to expenditure associated with the repository construction. Following the call for expressions of interest, three communities in Cumbria came forward: Allerdale Borough Council and Copeland Borough Council (located in West Cumbria adjacent to Sellafield), and Cumbria County Council. A high-level review of the geology in West Cumbria, conducted by the British Geological Survey (BGS)²³³ in October 2010, eliminated some areas under consideration, leaving open others which would require further geological investigation. The people of West Cumbria must decide in 2012 if they wish to continue in the site selection process.²³⁴ This model of a voluntary process of site selection is similar to that deployed in Sweden in 1992 that eventually led to the selection of Forsmark as the host for the Swedish GDF in 2009.

Academic social science studies exploring the comparative dimension of involving communities in finding a solution to geological disposal have concluded that simply transplanting a model that has been successful in one country to another is far from straightforward given the important differences in national political culture that exist. Experience shows, however, that it is possible to selectively use ideas and processes from one country and adapt them to the specific national and local context of another. Hence one has seen local authorities from a number of countries (Canada, UK, France, Belgium, Sweden, etc) sharing experiences and developing learning platforms over the last decade.²³⁵

²²⁸ Blowers A., Lowry D. and Solomon B. (1991): 'The international politics of nuclear waste' Macmillan: London

²²⁹ Nirex report (2002): 'Identifying public concerns and perceived hazards for the phased disposal concept' A summary report by The Future Foundation <http://www.nda.gov.uk/documents/upload/Identifying-public-concerns-and-perceived-hazards-for-the-PDC-Summary-2002.pdf>

²³⁰ Friends of the Earth Nirex Archive http://www.foe.co.uk/campaigns/climate/nirex_archive_19928.html

²³¹ Dunlap R. E., Kraft M. E., Rosa E. A., (Eds.) (1993): 'Public Reactions to Nuclear Waste: Citizens' Views of Repository Siting' Duke Univ. Press, Durham, NC

²³² National Research Council (2003): 'One Step at a Time: The Staged Development of Geological Repositories for High-Level Radioactive Waste' National Academies Press, Washington, DC

The process being followed for site selection in the UK recognises historical failings and best practice from other countries and emphasises volunteering as the driving principle. This process is not without risks in that the volunteer community may not have suitable geology for a GDF^{236, 237} or local commitment may fail. **It is apparent that there would be benefits from encouraging further communities to join those in Cumbria in exploring with the Government the pros and cons of hosting geological disposal.** Institutional 'body language' is vital to success, given that trust is very easy to lose and difficult to re(gain). It requires transparency and vigilance on the part of sponsoring organisations that must treat publics with respect. Addressing relevant social issues does not guarantee success, but ignoring them increases the chances of repeating past failures.

Conclusions and Recommendation:

- **In order to build public confidence that a viable solution to waste disposal exists, the scientific case for constructing a GDF in Cumbria should be developed as a matter of priority, explicitly addressing the outstanding criticisms from the 1997 RCF Planning Inquiry.**
- **As trust building and the generation of confidence are key for successful nuclear waste management, Government and the nuclear industry must actively engage robust (social scientific) research that explores, for example, influences on public opinion, and assesses the factors that contribute to confidence building and how to effectively integrate the best scientific data with lay understandings and knowledge**
- **The full range of scientific opinion on the geological conditions of sites must be made available to the public in a format and language they understand. This 'translation' of scientific data relies on 'honest brokers' and must be based on collaborative learning between stakeholders and the public.**

²³³ West Cumbria Managing Radioactive Waste Safely Partnership: Geological Screening <http://www.westcumbriamrws.org.uk/page/95/Geological-screening.htm>

²³⁴ West Cumbria Managing Radioactive Waste Safely Partnership: Public Consultation <http://www.westcumbriamrws.org.uk/>

²³⁵ For example the COWAM project(s) <http://www.cowam.com/>, the INSOTEC project <http://www.insotec.eu/>, the IPPA project <http://www.ippaproject.eu/> and the CARL Project (2006–2008) which all brought together citizen stakeholders, agencies and companies responsible for radioactive waste management, social science research organisations and licensing and regulatory authorities in a range of European countries. The projects examined the decision-making processes relating to radioactive waste management, key issues such as transparency and trust, how social science issues affect this process and how it can be developed to enable more effective stakeholder involvement, while meeting legislative requirements

²³⁶ Nirex (2001): 'The Scientific Foundations of Deep Geological Disposal' Nirex Report N/016, Nirex: Oxfordshire <http://www.nda.gov.uk/documents/upload/The-scientific-foundations-of-deep-geological-disposal-Nirex-Report-N-016-2001.pdf>

²³⁷ Cumbria County Council Appeal by United Kingdom Nirex Limited (1996) http://davidsmythe.org/nuclear/inspector%27s_report_complete.pdf

10

Nuclear education and skills

Addressing the ‘nuclear skills gap’ is a significant future hurdle for the nuclear industry. The issue has been documented many times over recent years²³⁸ and, in essence, stems from the past of nuclear energy in the United Kingdom.

10.1 Background

The UK had a significant lead in the early days of nuclear energy – in research, development, innovation, and reactor development (having the first nuclear power station to send significant quantities of electricity to a national grid – Calder Hall in 1956).²³⁹ This high level of activity continued for 10–15 years, but then declined in the 1980s and 90s as the prospects for nuclear energy in the UK looked bleak due to underinvestment. The single PWR at Sizewell B is the only civil nuclear reactor to have been constructed in the last 25 years in the UK.

The nuclear industry has evolved a highly polarized workforce age profile in line with these developments. Many workers are either skilled veterans, close to retirement, or are part of a ‘new wave’ of younger generation in their 20s. A key problem is ensuring knowledge exchange before the older generation retires. It poses an interesting challenge for the younger generation and all parts of the education cycle involved in preparing them for the industry. With the planning procedures and actual reactor build unlikely to come to full fruition until 2020, it is this new generation who will drive forward the industry and steer the future of nuclear energy over the next 60 years (the lifespan of the new generation of reactors).

Education at academic institutions (colleges and universities) provides the learning foundations before skills are applied and experience gained in the industry itself. The skills required vary over the different stages of a reactor’s life – particularly when comparing construction to operation and to decommissioning afterwards. Getting the portfolio of training opportunities right is essential to equipping the future generation with the required skills. The so-called ‘skills pyramid’ is one way of looking at the different levels and types of knowledge required. It depicts the educational programmes from entry level and apprenticeships through the foundation level and on through to Masters level degrees and PhDs. The structure of the industry as a whole is also an influential factor: part of it (such as consultancies) resides outside the actual power and utility companies, limiting (access to) internal training programmes.

A further concern is that in addition to the negative impact suffered by the industry during the economic downturn, the spread of universities with nuclear expertise has shrunk considerably. Furthermore, many of the groups that remain are subcritical in size and thus the ability to deliver coherent and comprehensive educational programmes is compromised. This is gradually changing, as research grants are being focused towards the nuclear area and

more research groups are developing nuclear-related interests. Correspondingly, new nuclear undergraduate and postgraduate programmes are appearing. However, continued development relies strongly on signals from Government as to the future of the nuclear industry and the direction of nuclear research.

The following explores how training and education is organised across further education (FE), higher education (HE) and industry.

10.2 Cogent and NSAN

The Cogent Sector Skills Council has undertaken research into the skills needs of a variety of nuclear industries.²⁴⁰ A series of reports from the last few years has highlighted the ‘skills gap’ in the nuclear sector described above^{241, 242, 243, 244}.

In the first of these reports²⁴¹ Cogent has attempted to predict the requirements of the Civil Nuclear Workforce for the period 2009 to 2025. Clearly, the results are a function of the uncertain nature of future developments of the sector. This is still true from a 2012 viewpoint where progress has been made on some fronts such as the Generic Design Assessments of new build designs but, on the other hand, the ongoing impact of the

²³⁸ Cogent: Nuclear Research – Renaissance Nuclear Skills Series <http://www.cogent-ssc.com/research/nuclearresearch.php>

²³⁹ Obninsk in Russia was the first Nuclear Power Plant to provide electricity to a ‘grid’, albeit only 5 MWe

²⁴⁰ Cogent <http://www.cogent-ssc.com/>

²⁴¹ Cogent (2009): ‘The Renaissance series: 1. Power People: The Civil Nuclear Industry 2009–2025’ Cogent SSC Ltd.: Cheshire http://www.cogent-ssc.com/research/renaissance_i.php

²⁴² Cogent (2010): ‘The Renaissance series: 2. Next Generation: Skills for New Build Nuclear’ Cogent SSC Ltd.: Cheshire <http://www.cogent-ssc.com/research/renaissancecell.php>

²⁴³ Cogent (2011): ‘The Renaissance series: 3. Assurance: Skills for Nuclear Defence’ Cogent SSC Ltd.: Cheshire <http://www.cogent-ssc.com/research/Publications/publications/Ren3Assurance.pdf>

²⁴⁴ A more international viewpoint is covered in the OECD’s Nuclear Energy Agency report ‘Nuclear Education and Training, From Concern to Capability’ (April 2012) <http://www.oecd-nea.org/ndd/reports/2012/nuclear-edu-training-ex.pdf>

Fukushima accident has delayed progress and led to yet more uncertainty (eg, the withdrawal of RWE and E.ON from Horizon Nuclear Power). As well as surveying needs by skill sector, the Cogent report also considers regional impact on requirements and availability. Their study categorised five skills levels: from semi-skilled (Level 1 NVQ/ SNVQ-equivalent) to skilled (Level 2 equivalent), to technician (Level 3 equivalent), to professional (Level 4 graduate equivalent), and finally to managers and senior management (Level 5 postgraduate equivalent). Their analysis shows electricity generation having the most skewed distribution towards the higher skill levels, with fuel processing being not far behind. Decommissioning shows the most symmetrical distribution. Having a disproportionate number of highly skilled people in particular areas is a consequence of under investment in training over a number of years and is clearly undesirable.

In considering age profiles and the impact of expected retirements Cogent has identified 2015 as a watershed year for skills: 'At this point many of the drivers of skills converge. By 2015, the retirement profile of the workforce begins to diverge significantly from that of the UK workforce; by 2015, the decommissioning of the old fleet will have taken hold; and, by 2015, recruitment and training for the new fleet must begin if the first are to commence operations from 2017.'²⁴¹

□ **Addressing the skills gap should be set as a high priority**

The second report 'Next Generation, Skills for New Build Nuclear'²⁴² views the requirements of the projected new build scenarios alongside the competition for manpower from other major projects such as Crossrail and 'M25 widening'. Clearly the demands for a skilled workforce depend on the size of the new build programme and between the publication of the Cogent report (2010) and now, there still remain uncertainties on the number of reactors that will be built. As a result the Skills Risk Register compiled in the report is based on a single reactor unit. For a total of 29 skill areas or competences the report estimates the number of staff at peak demand and through a combination of factors assessing probability of current skill deficit and demand timescale

allocates a high, medium and low rating to each of the 29. 11 are rated as High, 11 as medium and 7 as low [²⁴²– page 19]. This led the report to identify a number of skills 'pinch-points', in particular (i) project and programme management (ii) various aspects of engineering and (iii) safety and regulatory compliance.

Cogent produced a number of recommendations designed to address issues of capacity, capability and skills gaps. Under the main heading of Workforce Development it recommended action on apprenticeships and new entrants, foundation degrees and occupational standards. To promote workforce mobility they recommend skills accreditation schemes including the NSAN Nuclear Skills Passport; in addition they recommended activities by the sector skills bodies to assist transition planning where skills may be transferable from other industries. On education they recommend government, funding bodies and industry work collaboratively to ensure the appropriate supply of relevant courses at the FE, HE and postgraduate levels. In addition, it recommended that the sector skills bodies and industry work with schools, colleges and universities to raise the knowledge of the opportunities in the industry through activities such as 'nucleargraduates'.²⁴⁵

The third of the Cogent reports²⁴³ addresses the parallel aspects of Skills for Nuclear Defence. While the Defence Nuclear Programme forms a critical 25% of the total current UK demand for nuclear and nuclear related skills, there are a number of significant differences with respect to the civil sector. Therefore, in assessing the needs and availability of skills for the civil nuclear programme, it is necessary to bear in mind both the symbiotic relationships with the defence sector but also the competition for skilled workforces. The report provides a job context comparison between the civil and defence sectors across a dozen activities; greater detail can be found in the report.²⁴³

In recent times Cogent has liaised closely with the National Skills Academy for Nuclear (NSAN) to address various aspects of the skills requirements of the industry projected forwards. So far this has been particularly significant in promoting developments at the apprentice and foundation degree levels, where

large numbers of skilled workers are needed, but without degree level or postgraduate specialisation. Since workers with this type of expertise (such as mechanical and electrical fitters) are employable in other industries, it is particularly important to encourage them into the nuclear industry. Therefore the work of NSAN and Cogent in this area is vital.

Nuclear Island

In order to stimulate the growth of skills Cogent together with Imperial College London and the Royal Academy of Engineering, funded through the HE STEM programme, have developed the Nuclear Island programme.²⁴⁶ This is based at the Constructionarium in Norfolk and involves a two week programme to engage students on university civil engineering programmes in issues associated with the civil construction of nuclear power stations. The extension to mechanical and electrical engineering is currently being considered. Funding for the two-week courses is typically provided by an industrial partner. The value of the programme is widely recognised, but to-date the challenge has been securing sufficient industrial funding. Part of the challenge is to get significant industrial engagement for nuclear based projects from the construction section in advance of contracts for construction being signed. There is a danger that the significant potential benefits of such programmes, which provide an awareness of the different culture in engineering required for the nuclear industry, will be lost if significant sources of additional funding are not forthcoming.

□ **Consideration should be given to interim joint Government-Industry funding of educational and training programmes across the sector (FE and HE) to increase the volume of workers and students suitable qualified to work in the nuclear sector when new build commences.**

Some greater focus also needs to be directed to the university sector. While it could be argued that the university sector will regulate itself owing to supply and demand from the industry and students, there is a need for careful thought about the types of HE programmes that are required and an appropriate number of graduates.

²⁴⁵ nucleargraduates <http://www.nucleargraduates.com/>

²⁴⁶ Cogent: Nuclear Island http://www.cogent-ssc.com/Higher_level_skills/ni_index.php

This should also be appropriately matched to demand at different times of build and operation of plant. Such HE programmes cannot instantaneously generate graduates; there is a lag in time between proposing a new degree programme, having it approved by a university management system, taking admissions and the graduation of the first cohort. This can be of the order of five to six years at the undergraduate level and three years at postgraduate Masters level.

10.3 Requirements of the Nuclear Industry

One interesting challenge in matching the academic supply of graduates and apprentices to the demand from industry is the development of the skills profile required over time by the industry. Particular focus on such disciplines as civil engineering, building and construction will be required in the period of the new build expected in the UK. Estimates show the need for 30 nuclear engineers, 300 operations staff, and 3000 construction workers per reactor. The latter is an upfront effort, lasting of the order of five years, whilst the former two cover operations over a ~60 year period.²⁴⁷ However, the support structure of the industry around those reactors requires further specialist personnel. For example EDF Energy has many of its technical specialists based at Barnwood, while only some are located at the power stations. Similarly, the consultancies which support the industry are a further extension of this structure. The key point is that the 30 nuclear engineers per station applies only to staff on site: considerably more are needed for the industry as a whole.

Examples of roles where there is a concern that sufficient qualified people may not exist are: project managers with nuclear experience, non-destructive testing specialists, experienced high integrity welders, control and instrumentation engineers, safety case engineers, scientists (particularly chemists, physicists, and metallurgists/materials scientists), geotechnical engineers and environmental engineers. Whilst some of these areas require apprentice or foundation degree training, a number of these professions require specialist courses at the higher education level in the university sector.

These numbers are considerably larger when one considers the broader context of the industry in the UK. That is to say it is necessary to consider not just new build, but also operation of the existing fleet, decommissioning, plus other nuclear-related activities such as advanced reactor and fuel cycle development, fusion and nuclear-related defence activities including submarine propulsion. These areas largely tap into the same pool. Education and training has to be thought of in the broader context of the wider industry at the graduate level, just as it is at the apprentice level.

One important feature of the nuclear industry in the UK is that there is a strong desire to recruit graduates trained on high quality programmes. Consequently, a select number of universities and courses have been targeted by the industry for graduate recruitment. However, once in the industry, most companies will put students through graduate schemes or in-house training. This includes moving students around different parts of the company for placements, and also delivery of some in-house taught courses. Employees are given great encouragement to be members of professional bodies and, in particular, to hold chartered status. However, academic qualifications alone are not sufficient in the industry. Training for, and experience in, a role is also vital, and demonstration that someone is a 'Suitably Qualified and Experienced Person' (SQEP)²⁴⁸ is of great importance.

At the lower end of the skills pyramid some investment has already been made. An example is the investment in Bridgewater College (located near Hinkley Point) by EDF Energy for support to the first of their new EPR type reactors. NSAN has also developed a 'skills passport' for workers within the industry, and this is of particular relevance to skilled (but non-graduate) workers. On the graduate side, a new 'certificate of nuclear professionalism' developed by NSAN is operating through a combination of universities (developed by NSAN together with the Open University).

10.4 Educational Sector

It is not just the industrial side that may experience a massive shift in the near future. The university sector may experience significant changes owing to the tuition fees increase starting in 2012. Preliminary estimates indicate that the impact on student numbers is less significant in the engineering and science areas than in other areas such as social sciences. There may be reluctance for students to take on an extra year of debt associated with postgraduate programmes, which may deplete the numbers of graduates. This may further impact on the delivery of some science and engineering courses depending on the reaction of individual institutes to the new funding structures and associated student numbers. It may also be that students who are applying in the science and engineering disciplines become more selective about the universities to which they apply. Both industry and universities need to be alert to the implications of the changes to the student demographic.

One important aspect for the future is providing incentives for the really good students to come into the nuclear energy sector. This may take the form of bursaries from industry and/or research councils (EPSRC used to provide sponsorship to Masters programmes in this area), and may involve industrial projects and student placements. One potential sticking point is that industry needs confidence in the future direction (eg, of new build) in order to make financial commitments and investments in education and training. Likewise the university sector can have some inertia in terms of getting new courses approved and up and running. Therefore, there is some significant concern that trained graduates will not be in place when the demand finally materialises.

10.5 Apprenticeships and Foundation Degrees

The full supply chain to get a nuclear plant built and operating includes areas such as manufacture, construction, regulation, operations, power generation and plant maintenance (followed, eventually, by decommissioning). Although a significant number of the personnel required will need

²⁴⁷ These figures ignore the overhead incurred in the selection, assessment, safety approval and planning process prior to construction taking place. In addition, for the vendors there is the significant technical effort involved in the development, demonstration of principle and marketing of new designs, a process the UK have moved 'offshore'.

²⁴⁸ Office for Nuclear Regulation. An agency of HSE (2010): 'Technical Assessment Guide – Training and Assuring Personnel Competence', T/AST/027, HSE, ONR http://www.hse.gov.uk/nuclear/operational/tech_asst_guides/tast027.pdf

graduate or postgraduate training, most of the jobs created will be at a point in the skills pyramid before this – at the level of apprentices and foundation degrees (eg, the foundation degrees offered by the University of Central Lancashire, UCLAN). The exact numbers required depend heavily on the level of new build, but as an example a new build program at the order of 15 GWe generation would require tens of thousands of workers, with construction comprising about 60% of the workforce, operations 25%, and manufacture of the order of 15%. The construction of each nuclear reactor is a significant enterprise, comparable to building for the Olympic Games, so clearly careful planning and availability of the appropriate resources (including the workforce) needs to be mapped out. Significant 'staggering' between new reactors is likely to be needed – about 18 months between the start of construction of one reactor and the next (as has been done for example in China). The report by Cogent on skills for new nuclear build gives some indicative scenarios for how this may work in a way which starts to plug the energy gap around the latter part of this decade and then develops into a strong increase in nuclear generated power during the 2020s. Some other means may still be necessary to provide some of the shortfall created between about 2017–2020, however, and in hindsight this is a good reason for having acted sooner to facilitate new build in the UK. It is also an even better reason for moving forward and making progress **now**.

The sector skills council is working with the industry to pilot their Nuclear Apprentice Programme to operate across the nuclear sector. Combined with the Nuclear Passport scheme of NSAN this should help increase worker mobility as well as facilitate up-skilling and retraining. This may prove particularly useful because the apprentice level part of the skills pyramid tends to be more locally sourced (hence EDF Energy's investment in Bridgewater College). However, workers at the apprentice and foundation degree level can often go into a variety of areas of work (eg, welders, or electrical fitters, who can be general electricians instead of working at a power station), which means that the nuclear sector is fishing in a larger pool. Whilst the

established nuclear industry is putting funding into developing training in this area, due to the lack of clear signals regarding new build, other industries are not doing so to the same degree and that there is a danger that such programmes are significantly under-resourced.

10.6 University Sector

Undergraduate Degrees

No long-running undergraduate degrees in nuclear engineering exist within UK universities. There were some courses of this nature in the earlier years of nuclear power, but all were discontinued during the times of low demand from the industry. More recently, there has been a resurgence of nuclear engineering courses with new programmes at Lancaster University, Leeds University, Imperial College, the University of Birmingham, and the University of Manchester²⁴⁹. One useful aspect of undergraduate degrees is the wide-ranging focus, since the industry prefers to recruit chemists, materials scientists, mathematicians, physicists, engineers, economists, etc. Nonetheless, specialist nuclear education is often highly valued but this can be given only a limited coverage at undergraduate level apart from within specialised courses such as a nuclear engineering degree. As a compromise, the Imperial College degree allows students from a range of backgrounds (eg, mechanical engineering, chemical engineering) to take options in the latter part of their degree creating a 'with nuclear' degree. This provides some of the appropriate background and cultural awareness, and hence provides access to careers in the nuclear industry.

Postgraduate Masters Degrees

The only long running post graduate Masters course specifically aimed at the civil nuclear power area is the MSc in Physics and Technology of Nuclear Reactors at the University of Birmingham, which has run continuously since 1956. All other similar courses of the same vintage closed down, but in the last few years one or two other courses have started. These include the Nuclear Engineering Masters at Imperial College, the MPhil at Cambridge University, and the NTEC consortium (a collaboration between about a dozen universities, all

delivering modules towards a qualification in nuclear technology)²⁴⁹. The last of these is aimed particularly at industrial based students studying part time, but also has some recruitment of full time recent graduates. The Imperial College course started a couple of years ago and came online around the same time as Imperial's new undergraduate programme, and the Cambridge course has a focus that includes some of the social and political aspects.

In the broader arena, the University of Surrey has a set of radiation MSc courses that, whilst not reactor focused as such, have sent many people into various branches of the nuclear industry. Lancaster University also offers a safety course which includes aspects of nuclear safety. In the area of submarine reactors, as opposed to civil power generation, a long running course exists in the form of a suite of qualifications offered by the Defence Academy and delivered at HMS Sultan for the navy and related companies.

The Birmingham MSc in Physics and Technology of Nuclear Reactors provides an example of the benefits of close liaison between industry and the university. At a stage at the end of the 1990s when this MSc course was the sole surviving post-graduate course designed to supply graduates for the civil nuclear industry, it was faced with the loss of EPSRC studentships. It was through debate with and the positive support of the nuclear industry (and organisations such as the HSE) that a partnering agreement was set up to ensure the continuation of the course. The ongoing contribution of the industry to studentships and projects, together with significant in-kind assistance through talks and visits, has demonstrated an ongoing close collaboration between the industry and the course and its development. The high take up of graduates from the course into the industry has demonstrated that the 'product' is appreciated by employers.²⁵⁰

PhD Research Degrees

Nuclear-specific courses, of either the undergraduate or postgraduate Masters variety, largely closed down over the years where

²⁴⁹ Nuclear Liaison: University nuclear related taught courses in the UK <http://www.nuclearliaison.com/nl-courses>

²⁵⁰ The current contributors to the Partnering Agreement are: AMEC, Areva Canberra, Atkins, AWE, Babcock, BAE Systems, EDF Energy, Frazer-Nash, Horizon Nuclear Power, Magnox, National Nuclear Lab, Rolls-Royce, Serco, and Westinghouse.

nuclear suffered a dip in prospects, and the same is partially true of the research sector. This includes the training of postgraduate researchers such as PhD and EngD (see below) students. Funding for nuclear energy related research was reduced through the 1980s and 1990s. In response, research programmes moved more towards decommissioning and life-extension. The refocus on new build and a reinvigoration of the decommissioning and waste disposal and management programmes has seen a greater emphasis on supporting doctoral training centres.

The EngD or Engineering Doctorate qualification is similar to a PhD but with a taught component and includes some management modules designed to make research engineers into industry leaders and managers. It has been an interesting development in the nuclear field in recent years and certainly ensures a close link between the academic institutions and the industrial partners. The Nuclear EngD centre hosted by the Dalton Institute at the University of Manchester includes a number of university partners.²⁵¹

Since the programme started only in 2006 with the first students being recruited in 2007, only a few students have graduated. However, the degree of industrial engagement is good. Moreover, it is good to note that access to the programme has widened to include further universities in recent times. This is to be commended as there was some evidence at the beginning of the nuclear EngD programme that some existing research links between UK universities and industry were being broken because companies were concentrating on the new EngD route.

Subsequently, the Nuclear FIRST²⁵² doctoral training centre was also established (2009) as a joint Manchester–Sheffield initiative. In addition the KNOO (Keeping the Nuclear Option Open) and DIAMOND projects²⁵³ were funded by the EPSRC to maintain the research base and provide opportunities for

postgraduate training. This injection of funding has been an essential stimulus to re-growing the skills capacity in nuclear technologies. However, to widen the research base and capacity its impact needs to be broadened over the higher educational sector.

□ It is recommended that nuclear EngD programmes should be as inclusive as possible so that there is encouragement to the whole academic sector involved in nuclear power related activities.

Research facilities in the UK in the nuclear area, which are key for the training of young researchers, have been significantly reduced over recent years.²⁵⁴ One notable example concerns research reactors. Here the UK's last openly available research reactor, CONSORT at Imperial College, remains operational during 2012 but will then shutdown and enter a decommissioning phase.²⁵⁵ Also of significance are facilities to perform materials tests at high temperatures, pressures, and flow rates as well as to perform in situ materials damage studies in appropriate beam fluxes. Indeed, as an example, the School of Metallurgy and Materials at the University of Birmingham is developing facilities in both of these areas which will provide much needed training opportunities for young researchers. In addition, the UK National Nuclear Laboratory (NNL) active facilities at Sellafield and Springfields are available for researchers through NNL-NDA-University of Manchester third party access agreements. However, to date there have been only a limited number of projects utilising this opportunity and the mechanism, including funding routes, needs to be better understood. Similarly the Dalton Cumbria Facility offers new research and training possibilities.

Post-Doctoral Activities

While it is clear that greater efforts are still required at the lower end of the skills pyramid, it is worth noting, in conclusion, activities at the post-doctoral level. France (latterly in collaboration with Germany) instituted in the mid 1990s a programme of summer schools

designed for post-doctoral natural scientists in R&D laboratories, nuclear industry and utilities in order to address the challenges of the future, such as new reactor generations, optimal solutions for the back-end of the fuel cycle and the necessity for a fundamental understanding of nuclear physics. In doing so it aims to focus on the preservation of a high standard of knowledge in reactor physics and reactor technology. These Frédéric Joliot / Otto Hahn Summer Schools have attracted large multi-national audiences and have developed an enthusiastic international following.²⁵⁶

The UK has participated by providing a number of lecturers as well as students and one special autumn session was run in the UK.

More recently the National Institute for Nuclear Science and Technology (INSTN) and the Nuclear Energy Division (DEN) of CEA in France have formed an international school in nuclear engineering, aimed at promoting knowledge in the field of reactor physics and engineering at a high education level.²⁵⁷ These activities are also open to UK participants.

Conclusions

- Cogent are congratulated on their efforts so far and are encouraged to maintain their activities in assessing the needs for skills in the nuclear sector.**
- Close collaboration between industry and academia is vital to the production of suitably qualified persons for all stages of the application of nuclear energy and the nuclear fuel cycle.**
- Research degree programmes that encourage links between the nuclear industry and universities should be as inclusive as possible in order to nurture the small number of institutions active in this area.**

²⁵¹ University of Manchester, Dalton Nuclear Institute: Nuclear EngD <http://www.dalton.manchester.ac.uk/education/nuclear-engd/index.html>

²⁵² Nuclear Fission Research, Science and Technology Centre for Doctoral Training (Nuclear FIRST) <http://www.nuclearfirst.manchester.ac.uk/>

²⁵³ Engineering and Physical Sciences Research Council (EPSRC) Press release (2009): 'New generation of experts to solve nuclear skills shortage' <http://www.epsrc.ac.uk/newsevents/news/2009/Pages/nuclearskillsshortage.aspx>

²⁵⁴ Nuclear Energy Agency (NEA), Organisation for Economic Co-operation and Development (2009): 'Research and Test Facilities Required in Nuclear Science and Technology' OECD: Paris <http://www.oecd-nea.org/science/reports/2009/6293-Research-Test-Facilities.pdf>

²⁵⁵ Imperial College London: Reactor Centre <http://www3.imperial.ac.uk/reactorcentre>

²⁵⁶ Frédéric Joliot / Otto Hahn Summer School on Nuclear Reactors <http://www.fjohss.eu/>

²⁵⁷ International School in Nuclear Engineering http://www-instn.cea.fr/IMG/pdf/Leaflet_M3_2011_bat-3.pdf

Glossary

Term	Definition
Advanced Gas Cooled Reactor (AGR)	The UK's second generation of nuclear power stations, built between 1965 and 1989. These reactors use a carbon dioxide gas as the coolant. This is heated by passing through channels in a graphite moderator. The graphite slows the neutrons enhancing the fission probability.
Advanced Passive Reactor from Westinghouse (AP1000)	A Generation III+ pressurised water reactor (PWR). It is designed by the Westinghouse Electric Company. Features include enhanced safety. Several reactors of this design are currently under construction in China.
Boiling Water Reactor (BWR)	The second most common type of reactor in use worldwide. The moderator is water, which is allowed to boil and then passed through a turbine to generate electricity.
Breeding	Conversion of one isotope (such as ^{238}U or ^{232}Th), which in itself is not a suitable fuel for fission, into a different isotope which can fission in a reactor (eg, ^{239}Pu or ^{233}U). Reactors able to perform such a function are known as breeders, eg, fast breeder reactors (FBR).
Carbon capture and storage (CCS)	Sometimes referred to as carbon capture and sequestration. This is a technology which can remove CO_2 (carbon dioxide) emissions from the exhaust gases from typical power stations. The gas once captured is pumped and stored underground, for example in disused oil or gas fields. The technology remains to be demonstrated on an industrial scale.
Carbon floor price	Part of the Electricity Market Reform package – a variable tax on electricity generators which will ensure that their total cost per tonne of CO_2 emissions (from the tax, and buying ETS permits) rises at a predetermined rate over the coming decades.
Combined cycle gas turbines (CCGT)	Conventional power stations that burn gas to turn a turbine and then use the waste heat to create steam for a second turbine, turning a relatively high proportion of their fuel's energy content into electricity.
Contracts for differences	Financial contracts that make a payment relative to some other price, for example, 'topping up' the revenue received by a generator at times when the market price is low (see FIT with CfD).
Department of Energy and Climate Change (DECC)	The government department responsible for energy policy in the UK (http://www.decc.gov.uk/).
Disposal System Safety Case (DSSC)	A set of reports that cover the safety issues associated with the development of a geological disposal facility (GDF). This is the responsibility of the Nuclear Decommissioning Authority (NDA). See http://www.nda.gov.uk/aboutus/geological-disposal/rwmd-work/dssc/ for details.
Engineering and Physical Sciences Research Council (EPSRC)	The government-funded research council responsible for most of the university and similar research in the area of nuclear energy. The Science and Technology Facilities Council (STFC) also has a role in funding a spectrum of pure and applied physical sciences together with key facilities such as the Diamond light source.
Enriched	The isotopic ratio of a particular nuclide is raised above that which occurs naturally. For example, natural uranium has about 0.7% ^{235}U , but in many reactors this is enriched to about 3 or 4%.
Euratom	The European Atomic Energy Community. See http://www.euratom.org/ . The Euratom Treaty is one of the Treaties of Rome, originally signed in 1957, and brings together all EU Member States in cooperation in all areas of the peaceful use of nuclear technology, including research.
European PWR from Areva (EPR)	An evolutionary pressurised water reactor (PWR) of Franco-German design and marketed by the French company Areva. This has a generating power of 1.6 GW. The EPR is the design which is planned to be constructed at Hinkley point by EDF. Four reactors of this design are under construction in Finland, France and China.
Fast neutron reactors (FNRs)	Neutrons produced directly by fission are known as fast neutrons. In thermal reactors they are slowed down, moderated, to become thermal neutrons. Thermal neutrons are used in thermal reactors, fast neutrons in fast reactors. In order to sustain the chain reaction, typically higher levels of isotope enrichment are required. Fast reactors have the potential to produce waste with lower radiotoxicity which needs to be stored for shorter times.

Term	Definition
Fertile	Material suitable to be converted into a fissile fuel nuclide, eg, ^{238}U or ^{232}Th which are converted by neutron absorption and subsequent radio-active decay into ^{239}Pu and ^{233}U , respectively. These last two isotopes are fissile.
Feed-in tariff	A way of supporting generators which offers a fixed price for each unit of power that they generate. These have historically been used to permit renewable sources to establish themselves in the energy market.
Feed-in-tariff with contracts for differences (FIT with CfD)	Part of the Electricity Market Reform package that will effectively guarantee the overall revenue received by low-carbon generators holding these contracts, topping up their revenues when market prices are low and capping them when prices are high, but still requiring them to sell their power in the wholesale markets. As part of the Contracts for Difference it is necessary to get agreement on the Strike Price – this is the price that determines if the utility will either receive or give payments.
Fissile	An isotope that has a significant probability of undergoing fission (splitting into two fission fragments) induced by low energy neutrons (ie, thermal neutrons). Examples are ^{235}U , ^{239}Pu and ^{233}U . Some other isotopes can have a very small but finite probability of fissioning with thermal neutrons but they are not normally regarded as being fissile. An example is ^{238}U .
Fission	The process of splitting of a heavy nucleus into two or more parts with the release of energy. In a reactor, fission is induced by neutrons; however, a few heavy nuclides can undergo fission spontaneously without being stimulated through the absorption of a neutron, an example is ^{252}Cf .
Fission fragments	The heavy particles emitted by the fission process while they still have significant kinetic energy. It is this kinetic energy (energy associated with their motion) which heats up the fuel rods, which in turn is used to heat the coolant. The heated coolant can then be used to generate electricity using a turbine.
Fission products	The products resulting after fission fragments have lost their kinetic energy. They also include the daughter products after radioactive decay of other fission products.
Fusion	The merging of two light isotopes releasing energy in the process. An example is a deuteron (2H) and a triton (3H). In a fusion reactor, this process creates helium-4 nuclei and neutrons. The neutrons carry most of the energy which, in principle, may be converted into heat and hence electrical energy.
Generation IV / Gen-IV	A fourth generation reactor. Generation I were the first power producing reactors; Generation II the current power producing reactors; Generation III Advanced Reactors (usually certified by the NRC in the 1990s); Generation III+ designs which offer significant improvements in safety and economics over the Generation III advanced reactor designs; Generation IV concepts for future designs. These advanced reactor designs have a number of potential advantages over current reactor designs such as improved safety, higher efficiency and reduction in waste.
Generic Design Assessment (GDA)	The process conducted by the Office for Nuclear Regulation and the Environment Agency which performs a detailed review of the designs proposed to be built in the UK (EPR and AP1000). This is a pre-licensing process in which there is a detailed review of the design specifications of the reactors in the context of UK regulations.
Geological Disposal Facility (GDF)	An underground nuclear waste disposal facility for the disposal of intermediate and high level waste. The site would typically be 500 m underground in a geologically stable environment. The UK is currently in the process of exploring possible options for the construction of a GDF by 2040.

Term	Definition
GWe	A unit of power – many nuclear power stations are just over 1 GW in size, while the demand for electricity in Great Britain varies between around 30 and 60 GW. 1 GW = 1,000 MW = 1,000,000 kW. Giga Watt of electricity = 109 Watts. The 'e' stands for electrical as opposed to 'th' for thermal. This differentiates the thermal power (heat) produced by a reactor from the useful electrical power.
High level waste (HLW)	Radioactive waste that is sufficiently active that it generates significant levels of heat. Typically associated with spent nuclear fuels and reprocessing.
Intermediate level waste (ILW)	Radioactive waste that is considerably active but below the level of significant heat production. For example, decommissioning of nuclear reactors will produce ILW.
Irradiated material	Material that has been irradiated with some form of radiation, the term usually being applied to material that has become mildly radioactive as a result. In a reactor it is usually the neutron irradiation that is of significance. This irradiation may also change the structural properties, eg, causing embrittlement.
Isotope	An atom of a particular chemical element which has a particular number of neutrons in its nucleus. Specifying the elements defines the number of protons in the nucleus, but the number of neutrons can be different (eg, ²³⁵ U and ²³⁸ U are different isotopes of the element uranium).
Light Water Reactor (LWR)	A reactor that uses normal H ₂ O (water) as the moderator and coolant. In contrast, heavy water reactors (such as CANDU) use deuterated water D ₂ O. Deuterium is a proton and a neutron and is sometimes called heavy hydrogen.
Low level waste (LLW)	Waste with only low levels of contamination produced: for example, filters, clothing, waste from hospitals etc.
Magnox	Magnesium non-oxidising, being a magnesium alloy used to clad nuclear fuel in the Magnox reactors.
Magnox plants	The UK's first generation of nuclear power stations, built in the 1950s and 1960s; now mostly closed. A reactor that uses CO ₂ gas as coolant and graphite as the moderator. It is capable of operating with natural uranium in metallic form which is clad in a Magnox alloy fuel can.
Minor actinides (MA)	These are the actinide elements found in nuclear fuels aside from uranium and plutonium. These include elements such as americium, neptunium and curium.
Moderation	The process of slowing neutrons down from the energy at which they were emitted from the fission process until they are in thermal equilibrium with their surroundings and have enhanced probability for fissioning nuclei.
Molten Salt Reactors	A type of reactor in which the fuel is molten. The fuel can be dissolved in a molten salt coolant (eg, a fluoride salt such as uranium tetrafluoride). First developed in the US as part of the military programme and extensive tests were done in the 1960s at Oak Ridge National Laboratory in the US.
Mixed Oxide of plutonium and uranium (MOX)	A type of fuel which contains both uranium and plutonium in oxide form. The advantage of MOX fuel is that it does not require enriched uranium, since the fissile content is mainly provided by the plutonium, which is mixed with natural or depleted uranium.
National Nuclear Laboratory (NNL)	A government owned commercially operated (GoCo) laboratory in the UK which acts as the main centre of expertise on nuclear technology and the fuel cycle.
NIREX	The Nuclear Industry Radioactive Waste Executive, set up by the UK nuclear industry to manage the radioactive waste from the civil cycle. It was integrated into the NDA in 2006. It was charged with finding a geological disposal facility in the 1980s and 90s, a process that ended in failure.

Term	Definition
Nuclear Decommissioning Authority (NDA)	Organisation within the UK with responsibility for decommissioning and cleanup of nuclear facilities, including retired nuclear power stations in the UK. The NDA also has responsibility for developing a geological disposal facility (GDF) for the disposal of nuclear waste.
NRC	Nuclear Regulatory Commission. The organisation in the US responsible for the regulation, licensing and safety of nuclear energy.
ODS steel	Oxide dispersion strengthened steel – an advanced material currently under investigation for use in the nuclear sector.
Passive safety features	Safety features in a reactor design that do not require any power to make them operate – enhanced reactor designs contain such features.
Plutonium stockpile	The amount of plutonium that has accumulated from the operation of nuclear reactors and which has been separated from the spent fuel. The plutonium is separated from the spent fuel in reprocessing, where the unused uranium is removed from the plutonium and fission products and recycled.
Pressurised Water Reactor (PWR)	The most common type of reactor world-wide. The moderator is water kept under pressure, and a heat exchanger is used to create steam in a separate boiler circuit. The UK has one PWR, at Sizewell in Suffolk.
Prototype Fast Reactor (PFR)	Prototype reactor design using fast rather than thermal neutrons. The UK used to have a Prototype Fast Reactor at Dounreay in Scotland. This programme was stopped in the 1990s.
Sellafield MOX Plant (SMP)	The plant based on the Sellafield site which produced MOX fuel. Due to lack of demand and poor performance the plant is now closed.
Spent nuclear fuel	Irradiated nuclear fuel that has been discharged from a reactor. Depending on national legislation, is considered to be high-level waste for direct disposal in a GDF, or is reprocessed to extract uranium and plutonium for recycling in fresh fuel, with the remaining fission products and minor actinides sealed in a vitrified waste form for disposal in a GDF.
Spent nuclear waste	Waste from spent fuel, which needs to be disposed of in a geological repository.
Strike price	The average revenue that a generator with a feed-in-tariff with contract for differences (FIT with CfD) will receive; the level that its income is topped up to and capped at.
TSB	Technology Strategy Board, a publicly-funded body responsible for helping commercialise innovations in the UK See http://www.innovateuk.org/
Thermal Oxide Reprocessing Plant (THORP)	A plant operated by Sellafield Ltd and owned by the NDA used for the reprocessing of nuclear fuel. The uranium extracted from the spent fuel can be recycled into new fuel rods – eg, in MOX type fuel.
TWhr	A unit of energy – the UK generated 381 TWh of electricity in 2010. 1 TWh = 1,000 GWh; 1 GWh = 1,000 MWh and 1 MWh = 1,000 kWh. A typical UK household uses around 4,000 kWh per year.
Twin-unit station	A power station with two reactors on site.
W/m ²	Watts per square metre – useful in comparing the generating capacity of different types of technologies with national consumption. The UK's consumption is over 1 W/m ² and wind power can generate 2–3W/m ² . This would imply that if wind were the only source of electricity that one half to one third of the UK would need to be covered by wind turbines.

Appendix 1

Policy Commission work programme

The Policy Commission's work took place in two broad phases: **Phase One** involved establishing the Commission and scoping its topic; and in **Phase Two** – the main phase – the Policy Commission heard and deliberated evidence from a range of sources, agreed conclusions and recommendations, and explored them through the media and public events.

Phase One (July to November 2011)

Activities included:

- Developing the idea for the Policy Commission with University of Birmingham academics and Commissioners
- Launching the Policy Commission with a debate on 'Nuclear Power: What Does the Future Hold?', Chaired by the Vice Chancellor, at the Liberal Democrat Party Conference (September 2011). Speakers at this event included the Chair of the Commission – Lord Hunt of Kings Heath, Liberal Democrat MP John Hemming, Dr Susan Juned, Director, Greenwatt Technologies Sustainable Solutions, and Professor Martin Freer – Academic Lead of the Commission <http://www.birmingham.ac.uk/research/impact/policy-commissions/party-conferences.aspx>
- Commissioners' meetings to agree the content and process of the Policy Commission
- Contributing to the University of Birmingham meeting with Charles Hendry (Minister of State, Department of Energy and Climate Change)

Phase Two (December 2011 to June 2012)

Activities included:

- Two day-long workshops to hear and deliberate evidence from policy makers, practitioners and academics. These workshops attracted an impressive range of experts from within the UK and from France – a major player in the international nuclear arena. They included the Chairman of the UK Atomic Energy Authority; Senior Vice-President, AREVA UK; Vice President Europe Region, GE Hitachi; Director, Nuclear Energy Division, French Alternative Energies and Atomic Energy Commission; Head, Nuclear Development Division, OECD Nuclear Energy Agency; HM Deputy Chief Inspector, Office for Nuclear Regulation; Head of Nuclear Policy, EDF Energy; Communications specialist, Department of Energy and Climate Change; and the Public Policy Advisor, Nuclear Industry Association
- Commissioners' meetings to reflect on the issues raised at the workshops and deliberate policy options
- Meetings with key policy figures such as Dr Timothy Stone CBE (Expert Chair, Office for Nuclear Development; Senior Advisor to the Secretary of State for Energy and Climate Change)
- Meetings with organisations, such as the Weinberg Foundation, that were able to inform specific aspects of the nuclear debate
- Public presentations such as that by Professor Martin Freer at the Lunar society ('What should be the role of nuclear power in a secure future energy supply?', January 2012)

- Media briefings including a comment piece on Aljazeera <http://www.aljazeera.com/indepth/opinion/2012/03/201238115746998458.html>
- The Birmingham Brief: 'The need for a roadmap for nuclear policy', commenting on the status of nuclear energy on the anniversary of the Fukushima incident in Japan <http://www.birmingham.ac.uk/news/thebirminghambrief/items/The-need-for-a-roadmap-for-nuclear-policy.aspx>
- A public debate on the future of nuclear energy in the UK, held in Westminster (March 2012). Panellists included Lord Philip Hunt (Chair), Professor Martin Freer, Jonathon Porritt (Co-Founder, Forum for the Future), Keith Parker (Chief Executive, Nuclear Industry Association), Sue Ion (Former Group Director of Technology for British Nuclear Fuels Ltd) and Ron Bailey (Independent consultant). <http://www.birmingham.ac.uk/research/impact/policy-commissions/nuclear/publicdebate.aspx>
- Vice Chancellor's Select Dinner to discuss issues raised in the Commission with national experts including Norman Harrison (President, Nuclear Institute), Tony Grayling (Head of Climate Change and Sustainable Development, Environment Agency) and Alan Raymant (Chief Operating Officer, Horizon Nuclear Power).
- Commissioners' meetings to finalise the findings and recommendations

**Launch of Policy Commission Report:
02 July 2012**

Appendix 2

Contributors to the Policy Commission

Ron Bailey Independent Consultant

Professor Bertrand Barré Scientific Adviser to the AREVA President

Christophe Béhar Director, Nuclear Energy Division, French Alternative Energies and Atomic Energy Commission (CEA)

Dr Peter Burt Director, Nuclear Information Service

Ron Cameron Head, Nuclear Development Division (NDD), OECD Nuclear Energy Agency (NEA)

Professor Roger Cashmore Professor of Experimental Physics, University of Oxford; Chairman of the UK Atomic Energy Authority

Desmond Cecil CMG Senior Vice-President, AREVA UK

Neville Chamberlain CBE Chairman, Structure Vision Ltd

Professor Steven Cowley Chief Executive Officer, Culham Centre for Fusion Energy (CCFE) and Head of EURATOM/CCFE Fusion Association

JoAnne Fishburn Outreach Director, Weinberg Foundation

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Norman Harrison President, Nuclear Institute; Director of Strategic Development, Babcock International Group

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Rt Hon. John Hemming Liberal Democrat MP, Birmingham Yardley

Professor Karen Henwood Social Psychologist and Professor, Cardiff University

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