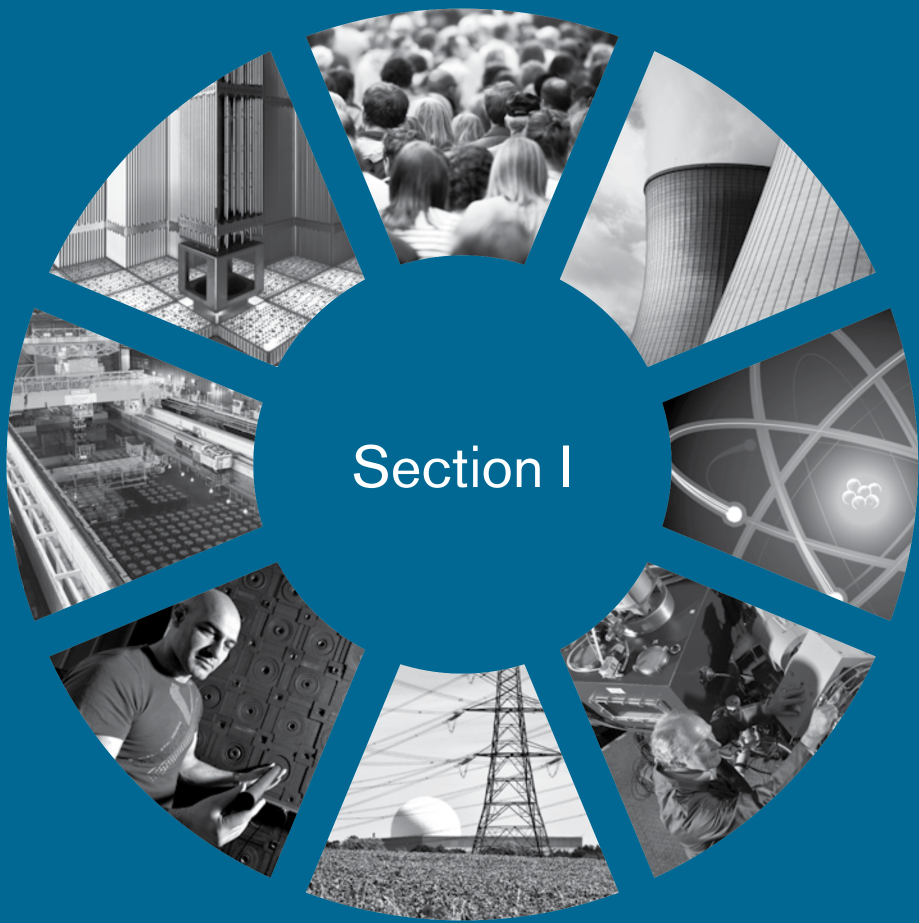
UNIVERSITY OF BIRMINGHAM

THE FUTURE OF NUCLEAR ENERGY IN THE UK

Birmingham Policy Commission

Summary Report
July 2012

Contents



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 Westinghouse[1] 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 Roadmap[5] 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/ldsctech/221/22102.htm

[5] Energy Research Partnership (2012): 'UK Nuclear Fission Technology Roadmap: Preliminary Report' http://www.energyresearchpartnership.org.uk/nucleartechnologyroadmap

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.

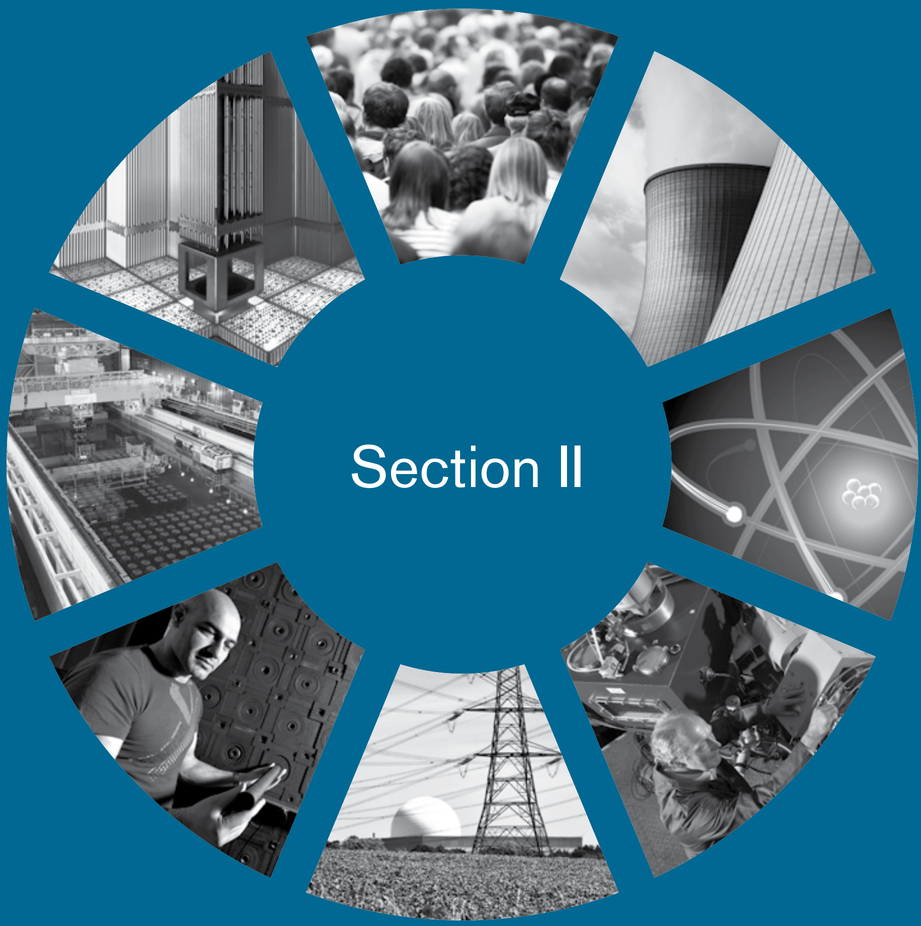
Launched with a debate at the Liberal Democrats Party Conference in September 2011, the Policy Commission ran until June 2012. Building on existing University of Birmingham research, and working with a range of expert contributors, it reviewed relevant research, received contributions from policy makers, 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, the Policy Commission Full Report contains a detailed analysis of the areas covered (please see www.birmingham.ac.uk/research/impact/policy-commissions/nuclear/indeax.aspx).

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.



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 the Policy Commission full report at:

www.birmingham.ac.uk/research/impact/policy-commissions/nuclear/index.aspx

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 century[7], 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 1997[10] 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 CO_2) 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 Deal[12]), 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 is a plausible solution? The answer is not trivial. The UK's road transport produces approximately 20%[13] of CO_2 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/m^2, 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/m^2, 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 CO_2 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 CO_2 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 developed[22] 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 CO_2 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 Reform[25]) 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 UK[27] – 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 budget[29] 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

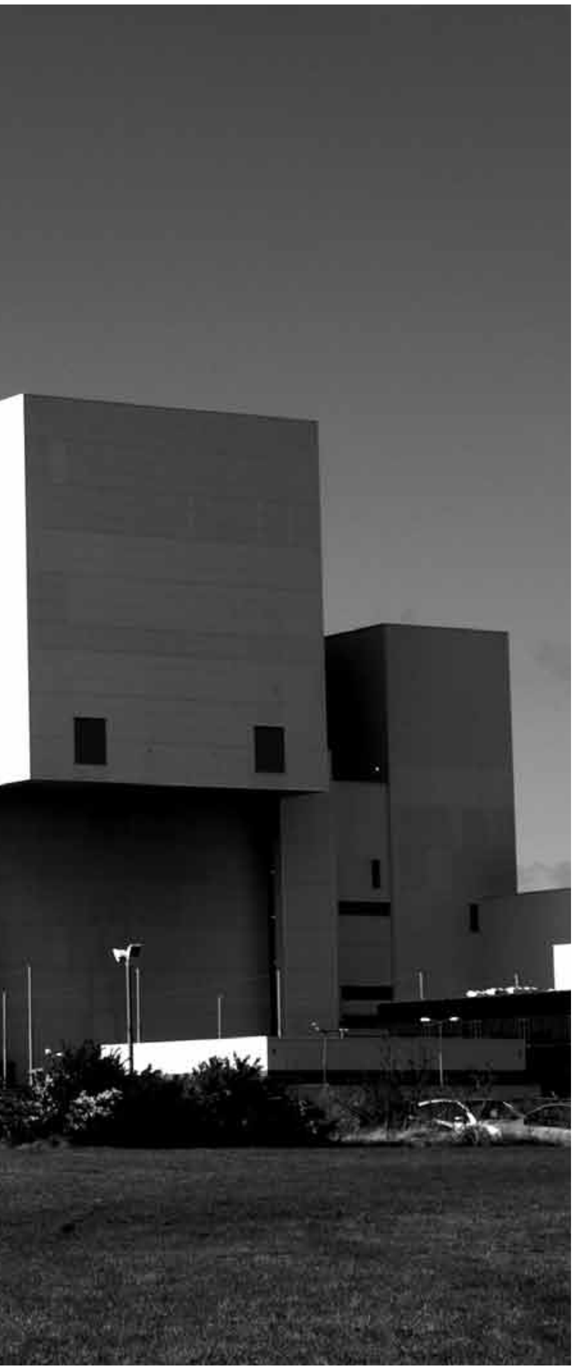
26 BBC News, 29 March 2012: 'RWE and E.On halt UK nuclear plans at Wylfa and Oldbury' http://www.bbc.co.uk/news/world-17546420

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 Reform[25] 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 CfD[25]). 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 though 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 report[39] (updated in 2008[40]) 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) call[42] 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 Government.[44] 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 Island[50] 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 College[52] 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.ashx

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 CO_2 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 ITER[54] 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

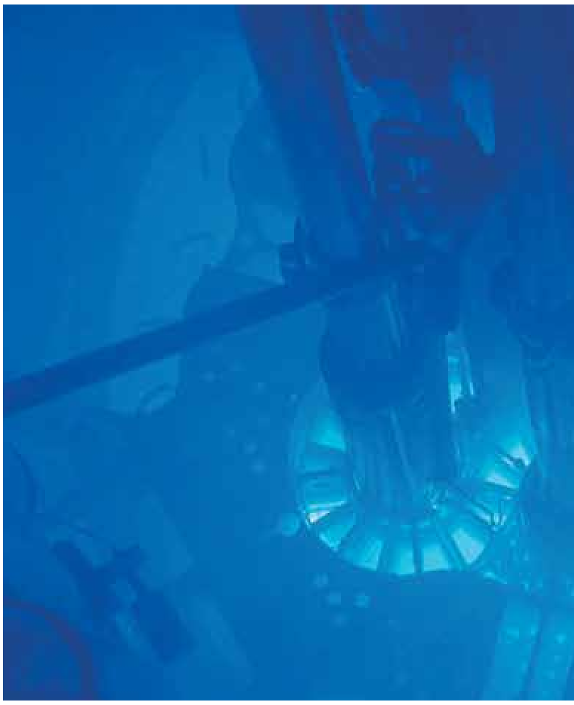
56 RWE: 'Deposits and extraction of Natural Gas' http://www.rwe.cz/en/deposits-of-natural-gas

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, ^{238}U (99.3%) and ^{235}U (0.7%), ^{235}U 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 (^{239}Pu) from the recycling (reprocessing) of irradiated fuel from current reactors. Crucially, this 'breeding' of fissile ^{239}Pu through nuclear transmutation of ^{238}U 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' (^{238}U '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 particularly, this would point to a focus on materials research and gas-cooled reactors – as recommended in the House of Lords report[4] – 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 PLUTO[60] 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

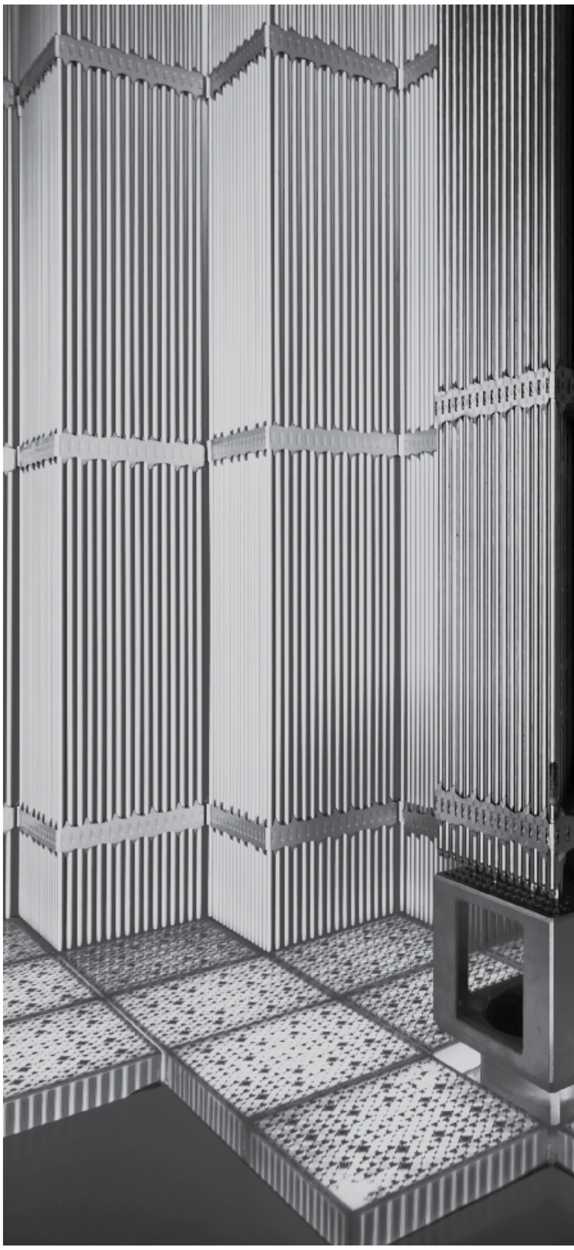
reactors explicitly exclude the consideration of MOX type fuels for these reactors. As a consequence, a new cycle of licensing and plant modifications will be required if MOX is to be the chosen route for the UK's plutonium stocks, resulting in further delays, risk and costs. It is a moot point whether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



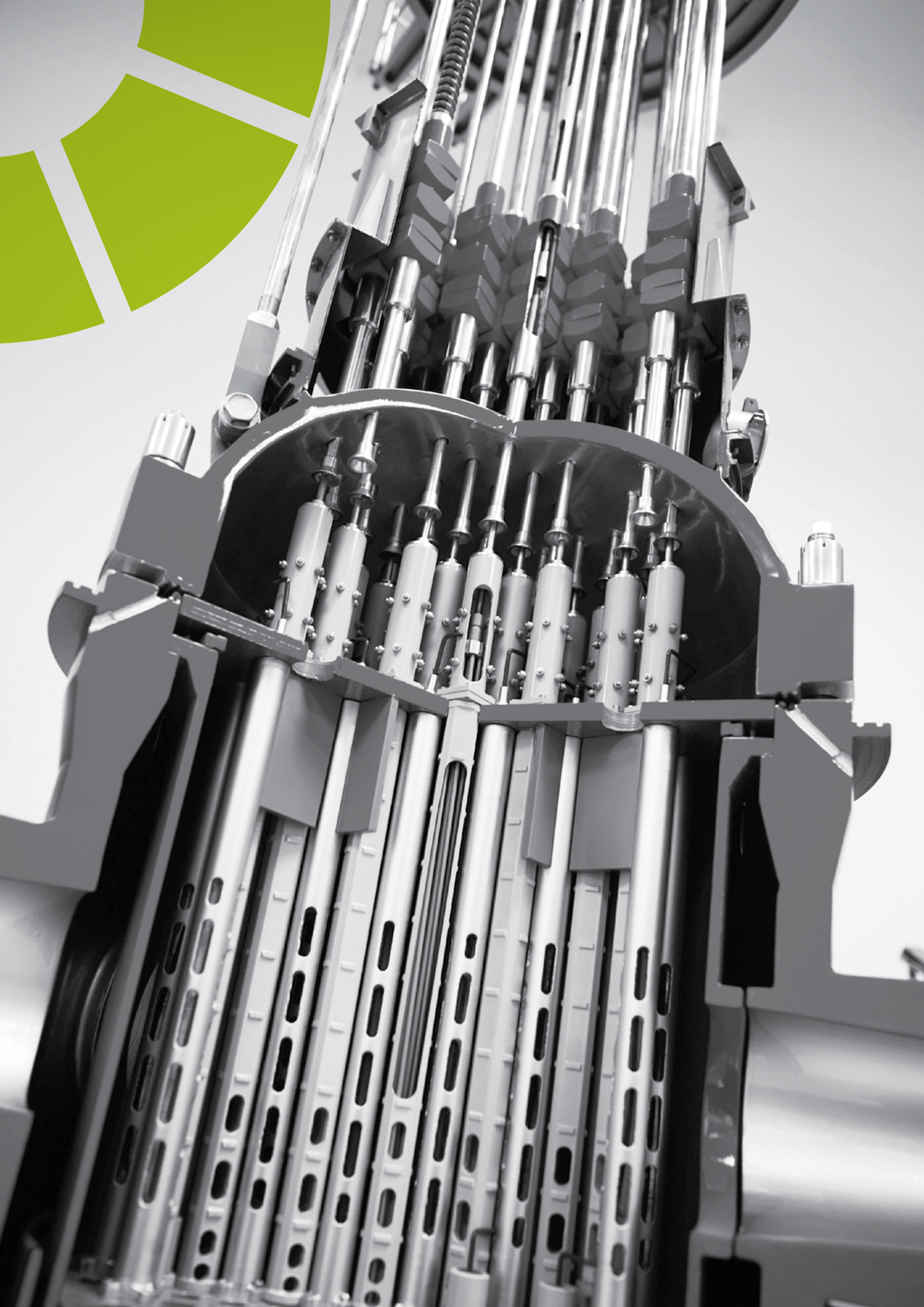
[61] GE-Hitachi: 'PRISM Sodium-Cooled Reactor' http://www.ge-energy.com/products_and_services/products/nuclear_energy/prism_sodium_cooled_reactor.jsp

[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 ^{23}2U, 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 designs[64] (eg, thorium oxide melts at a higher temperature than uranium or plutonium oxide – indeed, it has the highest melting point of all known oxides).

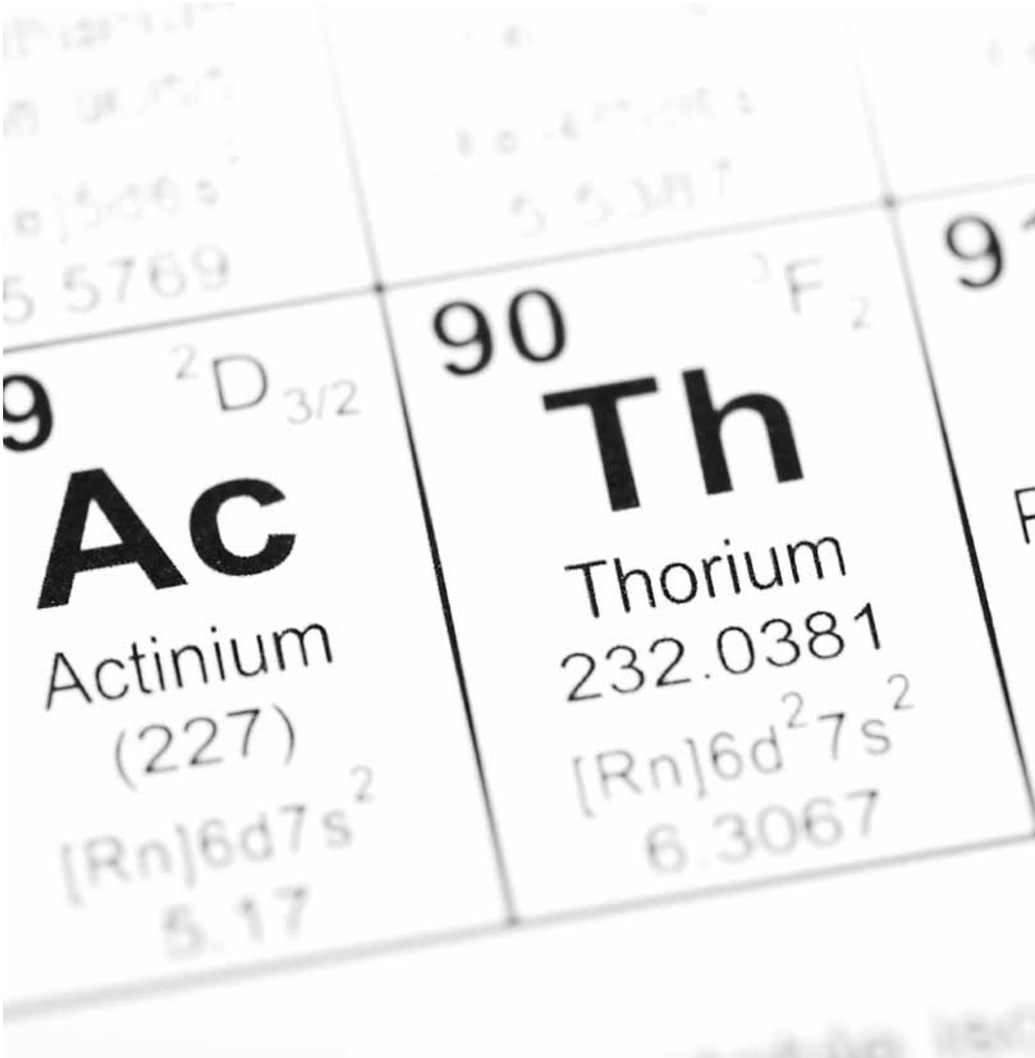
The concept was originally developed in the USA at Oak Ridge during the 1950s–70s, initially as part of the military programme and with the highlight being the operation, for four years at the end of the 1960s, of a lithium-beryllium-uranium molten salt reactor at ambient pressure and a temperature of 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.

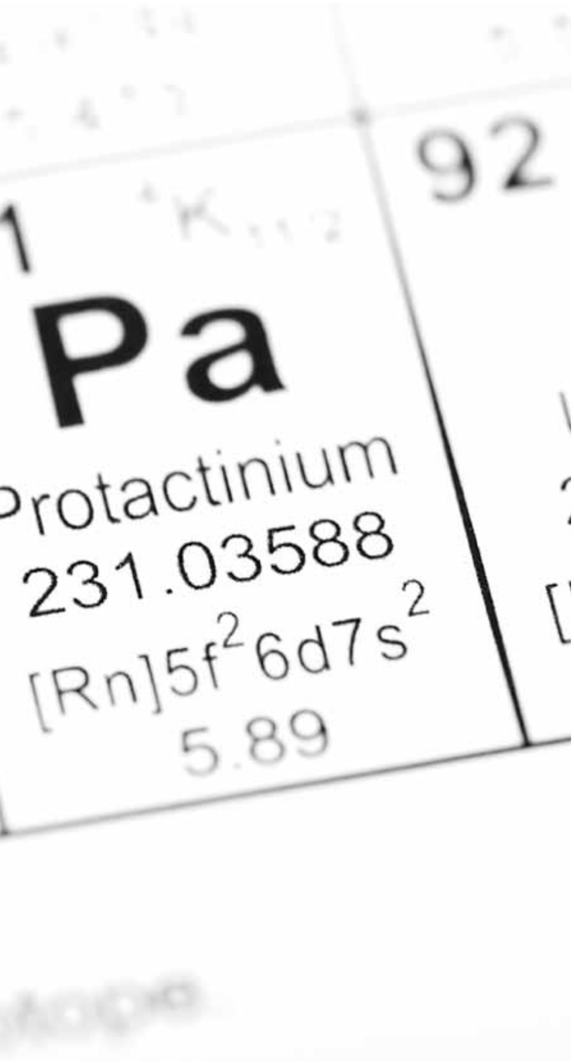
The Molten Salt Reactor is currently receiving a limited revival in interest by virtue of the fact it has been included as one of the six generic designs for investigation by GIF. It has also been argued that since the fuel is already molten, core meltdown issues are avoided. However, despite its inclusion 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://ripassetseu.s3.amazonaws.com/www.nnl.co.uk/_files/documents/aug_11/NNL__1314092891_Thorium_Cycle_Position_Paper.pdf

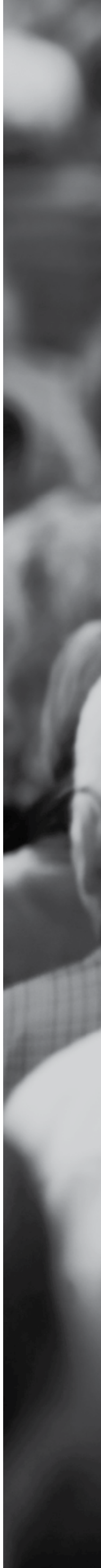


Conclusions and Recommendations

- **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 UK[70] – 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 initiative[73]). The latest UNSCEAR (UN Scientific Committee on the Effects of Atomic Radiation) 2011[74] 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 coal[78] 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 competiveness 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 m^3 and 1,020 m^3 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://ripassetseu.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 Kent[84]).

[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.

Timeline

1938
Discovery by Hahn and Strassmann of emission of barium following the bombardment of uranium with neutrons

1939
Meitner and Frisch interpret the energy emitting process and propose the term 'nuclear fission'

1940
Frisch-Peierls memorandum written from the University of Birmingham

1942
The first self-sustaining nuclear chain reaction was initiated in Chicago Pile-1. The reactor was made from a pile of uranium and graphite blocks

1943
Churchill approves the Anglo-US-Canadian Quebec agreement to collaborate on basic science and advanced engineering relating to nuclear energy – and weapons

1947
The construction of the first UK nuclear reactors at Sellafield starts – first fuel loaded 1950

1953
Construction of Calder Hall starts

1955
Government publishes white paper on 'A programme of Nuclear Power'

1956
Calder Hall (Magnox) opened by the Queen. Construction of Berkley and Bradwell (both Magnox) started

1957
Windscale accident. The reactor core caught fire releasing a large amount of reactivity into the local environment

1962
Berkeley and Bradwell commissioned

1963
The Windscale advanced gas-cooled (AGR) reactor commissioned first operation in 1962

1965
The UK decides on the advanced cooled reactor technology as the future for nuclear energy

1964–66
Hunterston A, Hinkley A, Trawsfynydd, Dungeness A and Sizewell A (all Magnox) commissioned

1967–71
Oldbury and Wylfa (Magnox) commissioned

1971
British Nuclear Fuels Limited (BNFL) formed to take control of fuel cycle – previously managed by UKAEA

1974
France decides on the PWR technology and starts to build a fleet of 34 such reactors

1976–85
The AGRs at Hinkley B, Hunterston B, Hartlepool, Heysham and Dungeness B (AGR reactors) commissioned

1979
Three Mile Island accident

1982
Nirex set up to examine possibility for deep geological storage in the UK

1983–85
Sizewell B public enquiry. The reactor is to be a PWR

1986
Chernobyl nuclear accident

1988
Construction of Sizewell B starts

1988–89
Heysham II and Torness (AGR reactors) commissioned

1989
Electricity Act – privatisation of electricity supply in UK

1990
Privatisation of the Central Electricity Generating Board CEGB. This resulted in the formation of National Power and PowerGen (generating companies) and the National Grid Company. National Power then became Nuclear Electric Plc

1994
THORP reprocessing plant opened at Sellafield – reprocessing spent nuclear fuel

1995
Sizewell B (PWR) commissioned

1996
British Energy privatised

1997
Two nuclear waste stores to be built at Sellafield, to take intermediate-level waste for the next 50 years

1997
Sellafield MOX plant completed. Plant manufactures MOX fuel (uranium plus plutonium oxide)

2003
Energy White Paper

2004
Nuclear Decommissioning Authority formed to decommission and clean up UKs civil nuclear legacy

2005
Large rises in electricity, gas and oil prices

2006
Energy review by the Labour government

2007
Labour government releases report 'The Future of Nuclear Power'

2007
Generic Design Assessment of potential nuclear reactors for the UK starts. This includes the assessment of the EPR and the AP1000

2008
The National Nuclear Laboratory formed (from Nexia Solutions a derivative of the former BNFL)

2008
Energy Act Implements White paper of 2007 'Meeting the Energy Challenge'

2009
EDF takes over British Energy

2010
Government gives the go-ahead §to build 8 new nuclear reactors

2011
Fukushima nuclear accident

2011
Government release white paper on Electricity Market Reform (EMR) proposals

2011
Office for Nuclear Regulation (ONR) formed. ONR was formed from the HSE Nuclear Directorate, initially as a non-statutory body, with the intention of being created as a statutory body at some stage in the future. The Dept Transport activities joined ONR in October 2011

2011
Sellafield MOX plant closes

2011
Royal Society report 'Fuel cycle stewardship in a nuclear renaissance'

2011
House of Lords Science and Technology Committee release their report on 'Nuclear Research and Development Capabilities'

2040–2050?

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