IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE

Faculty of Life Sciences

(University of London)

Department of Environmental Science & Technology

What does it mean to keep the nuclear option open in the UK?

By

Till Stenzel

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DECLARATION OF OWN WORK

I declare that this thesis

'What does it mean to keep the nuclear option open in the UK?'

is entirely my own work and that where any material could be construed as the work of others, it is fully cited and referenced and/or with appropriate acknowledgement given.

Signature:

Name of student: Till Stenzel

Name of supervisor: Dr. Peter Pearson

ABSTRACT

This study analyses what is required to keep the nuclear option open in the UK. It analyses four areas: The Economics of Nuclear Power, Radioactive Waste Management, the UK skill base and Safety and Security Implications of recent terrorist events. In each area, those aspects that influence the nuclear option are outlined and possible policy responses are discussed. A short-term and a long-term perspective on the nuclear option is considered.

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Glossary

AECL	Atomic Energy of Canada Ltd.
AGR	Advanced gas cooled reactor
ALARP	as low as reasonably practicable/possible
AP1000	Advanced Passive 1000MWe reactor, built by →BNFL/Westinghouse
APS	Automatic Protective System
BNFL	British Nuclear Fuels plc
BE	British Energy plc.
BNES	British Nuclear Energy Society
CCGT	Combined-Cycle Gas Turbines
CEO	Chief Executive Officer
CoRWM	Committee on Radioactive Waste Management
CPD	Continuous Professional Development
CSR	Corporate Social Responsibility
DBT	Design Basis Threat
Defra	Department for Environment, Food and Rural Affairs
DoE	US Department of Energy
DoH	Department of Health
DTI	Department of Trade and Industry
ENEN	European Nuclear Engineering Network
EPRI	Electric Power Research Institute
HLW	High Level Waste
HM	Her Majesty's
HMSO	Her Majesty's Stationary Office
HMT	Her Majesty's Treasury
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency (UN-sub-organisation)
ICE	Institution of Civil Engineers
ICRP	International Commission on Radiological Protection
IEA	International Energy Agency

ILW	Intermediate Level Waste
IMechE	Institution of Mechanical Engineers
kWh	kilo-Watt hour
LLW	Low Level Waste
LUC	Levelized Unit Costs
Magnox	Magnesium Alloy
MoD	Ministry of Defence
MWe	Mega-Watt peak, the potential (‘rated’) output of a power station
MWh	Mega-Watt hour
NDA	UK Nuclear Decommissioning Authority
NEA	Nuclear Energy Agency (OECD-sub-organisation)
NEI	US Nuclear Energy Institute
NERC	Natural Environment Research Council
NFFO	non-fossil fuel obligation
NG CANDU	Next Generation Canadian Deuterium Uranium Reactor, by →AECL
NIA	Nuclear Industry Association
NII	Nuclear Installations Inspectorate
Nirex	Company, founded under the initial name of Nuclear Industry Radioactive Waste Executive in 1982, to advise on radioactive waste
NPV	net present value
NRC	US Nuclear Regulatory Commission
NSS	DTI Nuclear Skill Study (2002)
OCNS	Office for Civil Nuclear Security
OECD	Organisation for Economic Cooperation and Development
PIU	Performance and Innovation Unit, now part of the UK Prime Minister’s Strategy Unit
PRA	Probabilistic Risk Assessment
PWR	Pressurised Water Reactor
R&D	Research and Development

RCF	Rock Characterisation Facility
RSK	Reaktor-Sicherheitskommission (German reactor safety commission)
SAP	Safety Assessment Principles
SQEP	Suitably Qualified and Experienced Person
SSC	Sector Skills Council
ToR	Tolerability of Risk
UKAEA	United Kingdom Atomic Energy Authority
UMIST	University of Manchester Institute of Science and Technology
URA	BNFL University Research Alliances
WANO	World Association of Nuclear Operators
WNO	World Nuclear Organisation
YGN	Young Generation Network of the →BNES

List of Figures

List of Textboxes

List of Tables

Chapter 1 Introduction

“Originally, nuclear power was deemed dirty but cheap; nowadays, in the face of Global Warming, it is deemed expensive but clean.” anon

1.1. Aims

This study aims to explore what may be required to keep the nuclear option open in the UK. A recent study by the UK Prime Minister’s Performance and Innovation Unit (PIU) (2002a) and the subsequent Department of Trade and Industry (DTI) White Paper (2003a) on energy policy declared that although no new nuclear build was currently planned, the nuclear option should be kept open. DTI (2003a:12) states that *“…we do not rule out the possibility that at some point in the future new nuclear build might be necessary if we are to meet our carbon targets.”* However, both reports have fallen short of explicitly laying out what this policy entails.

This study will stop short of arguing *whether* the UK needs to keep the nuclear option open or not. It was considered that in order to make a statement on the *whether or not,* it is necessary to analyse the conditions that underlie it. IEA (2002:136) considers it a key task for the UK government to “clarify how it intends to keep the nuclear option open”. Thus, this study can be seen as important in its own right, since it draws together several key areas in nuclear policy and hence allows a more informed judgement on the specific requirements such an option would demand to be satisfied. This in turn can then be seen as an important contribution to the question of whether the nuclear option *should* be kept open.

1.2. Objectives

In order to evaluate what is needed to keep the nuclear option open, this study will specifically analyse four issues that are seen as relevant. Those issues could be summarised under the following headings: Economics, Waste Management, the UK nuclear skill base and safety and security. Each will be analysed from the angle of steps needed in order ‘to keep the nuclear option open’. During the initial background research period, it was decided to apply different research foci on the above topics. Thus the first two areas of economics and waste management will be mainly covered by critically reviewing secondary sources. Conversely, semi-structured interviews were the chosen research method for the latter two areas of the UK skill base and safety and security. This was for two reasons: Firstly, time and resource constraints would not have allowed to carry out detailed research into all four issues. Nevertheless, the fact that one issue was treated in a less detailed way than another does not imply that it is necessarily less relevant. Secondly, as will be explained in more detail below, while the areas of economics and waste are relatively well established, the issue of safety and security and the UK skill base have only recently gained prominence, albeit for different reasons. In order to justify the approach adopted, each of the four issues will now briefly be discussed in turn.

As will be shown in section 3.2., the economics of nuclear power have been debated almost as long as it has been a commercial industry. The expected and actual costs of nuclear power have been subject of repeated debates. Also the role of discount rates and role of government in nuclear build programmes were subject to recurrent discussions (Williams 1980). These issues will be taken up again and their importance for the research question will be considered.

Nuclear waste was a hotly discussed issue when Nirex applied for a Rock Characterization Facility (RCF) near Sellafield in the mid-1990s. The ensuing public inquiry, which lasted from 1994 to 1996, produced a host of information on the issue. After the rejection of Nirex's application in 1997, a new consultation programme was started to determine the future course of a UK radioactive waste management strategy. The White Paper "Managing Radioactive Waste safely" (2001)[1] established a new beginning for reaching a decision, but a firm roadmap for the final route of radioactive waste is still to be decided. In the light of these events and given the fact that the issue will only reach more prominence on the political stage once the present consultation period is finished in 2005/2006 (Defra 2003), it was decided again that it would suffice to outline the issue in form of a literature review. Options for waste management and the state of current policy developments will be reviewed in section 3.3.

A recent development in the nuclear skills sector was a report by the DTI nuclear skills group (2002), which undertook to review the current and future requirements of nuclear and

[1] Somewhat ironically, the White Paper was officially published on 12 September 2001, the day after the terrorist attacks in the USA

radiological skills. This study aimed at the full spectrum of skills in this sector, from e.g. radiotherapy to nuclear submarine operator but did not focus specifically on the requirements for the nuclear option in the UK. Thus, it could be asked, what impact the current "wait-and-see" approach to nuclear power has on the nuclear skills base, and what those conclusions mean for the future ability of the UK to accommodate a nuclear industry over different timeframes and in different sizes. This is a very recent point of interest and thus it was felt that more detailed research in this area was needed, given especially that little detail was provided on the issue in PIU (2002a) and DTI (2003a).

Lastly, the terrorist attacks of September 11, 2001 (subsequently referred to as 9/11) brought about a widespread media coverage on the potential threat of terrorism to nuclear facilities. The USA established no-fly zones around all its nuclear facilities in the immediate aftermath of 9/11, while France moved a battery of anti-aircraft missiles to its reprocessing plant in La Hague. Now that the smoke has cleared, the question that has to be addressed more fundamentally is what impact these events have on 'the nuclear option'. The angle that will be taken in this study is twofold. It will firstly ask what direct economic cost implications on existing and new reactors could follow from 9/11 which in turn could impinge the nuclear option in the UK. Secondly, indirect consequences of economic and political nature have to be addressed. These include regulatory changes, planning issues and the general question of public acceptability of nuclear power. Since there is as yet little reliable data and independent opinion synthesized on this topic, apart from widespread media coverage on the potential threat of terrorist attacks on nuclear installations, this seemed again an important reason for studying this topic in more detail[2]. The results will be presented in Chapter 5.

1.3. Timeframe

An important task in this introduction now has to be to define exactly what is meant by 'the nuclear option'. In principle, it could be anything from sustaining an integral UK nuclear industry, capable of serving the whole nuclear product chain, to the construction of more interconnectors between the UK and France and tapping into the nuclear capacity existing there. For the purpose of this study, two timeframes will be considered. Firstly, the timeframe will be set by the current policy environment. DTI (2003a) sets out that a review in 2005/2006 will evaluate the progress achieved with the current energy white paper up to then and if

[2] At the suggestion of the Defence Select Committee of the UK House of Commons, the Parliamentary Office of Science and Technology is due to publish a report by the end of October 2003 on "the risks and consequences of a terrorist attack in a nuclear installation in the UK".

necessary adjust the energy strategy. Thus, keeping the nuclear option open in this context is essentially a short-term task. Secondly, the timeframe will follow expected technological developments. Here the timeframe around 2020 is a crucial reference point, since new developments which have just been started by the Generation IV international reactor research programme promise to show first results (Generation IV 2003). In this respect, keeping open the nuclear option requires long-term strategic action. The outcome of this study aims to identify the different tasks needed in both scenarios.

1.4. Structure

In summary, this study will explore four dimensions to the question of what it means to keep the nuclear option open in the UK. While the economics and future waste management will be addressed through a literature review, this paper's research will focus especially on the safety and security and the skill issue. Its objective is to determine in each area the active tasks necessary to keep the nuclear option open in the UK. In the light of these priorities, the structure of this study is as follows:

Chapter 2 introduces the methodology used in this study. It outlines the background research, the reasons for selecting semi-structured interviews as the preferred method and how these interviews were conducted.

Chapter 3 will begin with a brief historic overview of nuclear power in the UK. Subsequently, it present the results of a literature review on the economics of new nuclear power and the waste management issue. The aims here are twofold: Firstly, a general discussion on each issue is presented so as to characterize the key issues in both areas. Secondly, their relationship to the initial research question is highlighted and policy options will be discussed.

Chapter 4 analyses the UK nuclear skill and knowledge base. Findings from the literature review and the interviews conducted will be presented and their implications for the nuclear option will be analysed.

Chapter 5 will introduce the safety and security issues. It will provide a brief background of traditional safety measures at nuclear power plants before the main discussion will focus on the cost implications of the terrorist attacks of 9/11 for existing and new reactor designs. The last part of the analysis will highlight the potential tension that might exist between the need for confidentiality of information and the public request for openness and transparency.

Chapter 6 will bring together the results of the preceding chapters. It will critically evaluate the findings and the extent to which the original objectives were met. It will indicate areas for future research and in conclusion, discuss the policy options in order to keep the nuclear option open in the short- and long-term in the UK.

Chapter 2 Methodology

This chapter will introduce the methodology that was used in the course of the research for this study. The research was undertaken in collaboration with the UK Parliamentary Office of Science and Technology (POST). POST is an office of the two Houses of Parliament (Commons and Lords), charged with providing balanced and independent analysis of science and technology based issues of public policy. Throughout the research, this study was able to draw on the resources provided by POST, not least on the people working there themselves. In addition to this thesis, a four page parliamentary briefing (POSTnote) will be produced and be distributed to over 600 parliamentarians, peers and other interested parties on the POST mailing list. The draft parliamentary briefing note will be issued for peer review by October 2003 and be published thereafter.

The structure of this chapter is as follows: Firstly, the background research on the topic, and the reasons for dividing the research approach between the different aspects of the research question are outlined. Secondly, it will discuss in more detail why semi-structured interviews were used for chapters 4 and 5. Lastly, it will explain in more detail the interview process, choice of interviewees and the problems encountered during the research for each of the two chapters.

2.1. Background Research and Literature Review

An initial overview on the issue of the 'nuclear option' was conducted through a literature review, web and online journal searches for keywords, the study of government, official agency and 'grey literature' material, the attendance of seminars and events related to the topic and informal discussions with experts in the field.

Initially, the library catalogues of the Imperial College library as well as the British Library of Political and Economic Science were searched for key words. Similarly, large online journal catalogues such as Science Direct, Ingenta and JSTOR were searched for those keywords. Official publications from Department of Trade and Industry (DTI), the Department of the Environment, Food and Regional Affairs (Defra), the Parliamentary Office of Science and

Technology (POST) and the Policy Innovation Unit (PIU), publications by international organisations such as the International Atomic Energy Agency (IAEA), the Nuclear Energy Agency (NEA) or the Organisation of Economic Cooperation and Development (OECD) and company literature of e.g. British Nuclear Fuels plc. (BNFL), British Energy plc. (BE) and Nirex provided a further source of information. The aim at this stage of the research was firstly, to get a better understanding of the history of the nuclear power sector in the UK and secondly to identify key issues that relate to the research question. Here, Hall (1986) and Williams (1980) provided a comprehensive introduction into past nuclear power programmes initiated in the UK. Their discussion on the economics of nuclear power and the political decision-making also introduced important issues of today's arguments on keeping the nuclear option open.

Finally, a number of events, as described in Appendix 1, were attended. They provided the opportunity to discuss, informally, with representatives from industry, academia and NGOs issues related to the research questions. The presentations and panel discussions were furthermore a useful insight into the range of arguments that existed in the area.

The results from this initial research period, led to focus on the four topics outlined in chapter 1. However, during this research it became also evident that the material available on the issues of the UK skill base and the security and safety of nuclear power stations was very thin and disproportionately non-academic literature based. In contrast, the issues around economics and waste were long established and relatively well covered in the literature. Consequently, it was decided to cover these two issues largely through a literature review. Also, where necessary, certain key topics were identified for further interviews with a number of stakeholders. They were used as the basis for more specific and probing questions. These interviews were used to gain specific insights to central issues of the chapters. Freedom to discuss these areas of interest was instrumental in order to fully explore certain ideas and issues (Saunders, Lewis and Thornhill 2003). The lack of standard questions at this research stage raises concerns as to the reliability of the outputs. Associated difficulties include ensuring that biases are ruled out (Robson 2002). However, it was felt that this form of unstructured informal interview offered the most appropriate opportunity to quickly gather rich and instructive background material to compare and contrast with the findings of the literature review. Annex two summarises the contacts from these interviews.

2.2. Semi Structured Interviews

On the nuclear skill base and safety and security aspects of nuclear power, it was decided to undertake interview-based research. As the information available on both topics was thin the main aim of these interviews was to explore the topics more extensively and to try and identify the key issues in the both areas. Also, with a number of different stakeholders in both issues, it was important to elicit reasonings and framings of the argument from the various perspectives. With this in mind, a structured questionnaire or interview would have constrained the amount of information that could be collected for the topic. Also, "standardised questions work best when you can be confident [that they] will be interpreted the same way by all respondents" (Saunders, Lewis and Thornhill 2003:281). Given the different backgrounds of the interviewees, this could not be guaranteed. Furthermore, there were few topics with a straight forward yes/no answer which could have had accommodated a statistical questionnaire and subsequent analysis.

Instead, it was decided to use a semi-structured interview approach which was deemed suitable for two main reasons. In an exploratory study, semi-structured interviews can be helpful to 'find out what is happening and to seek new insights' (Robson 2002:59). Furthermore, they are helpful to "understand the reasons for attitudes and opinions of the interviewees" (Saunders, Lewis and Thornhill 2003:250).

It the next two sections it will now be outlined, what interview partners were chosen, how the interviews were conducted and what problems existed with each of them.

2.2.1. Semi-Structured Interviews for Chapter 4 – The UK nuclear skill base

A comprehensive background document on this topic was the Nuclear Skills Study conducted by the DTI (DTI 2002). Key stakeholders were identified on the basis of this and also through suggestions by members of staff at POST. Also, each interviewee was asked to recommend additional contacts thus creating a 'snowball effect' for further contacts. It was decided to focus on broadly four main stakeholders: the nuclear industry, government departments, nuclear regulators and academia. Interviews were conducted where possible but in some cases this had to be substituted for email exchanges. The list of people interviewed for this chapter is below. The names are listed together with their title and the method of exchange:

Industry:

- John Haddon, Head of Trade and Industry, NIA, meeting 5 August 2003
- Dr. Paul Howarth, Head of Group Science Strategy, BNFL, meeting 28 August 2003
- Richard Mayson, Technology Director for Reactor Systems, BNFL, meeting 26 June 2003
- Alistair Smith, Corporate Development Manager of NNC and Member of the Energy Working Group of the Institution of Mechanical Engineering (IMechE), Telephone and Email 3 September 2003
- Energy Board of the Institution of Civil Engineers (ICE), Head: Donald Anderson, Scottish Power

Regulator:

- Bill Ascroft-Hutton, Senior Inspector in Division 1 of the NII, responsible for all nuclear power stations in the UK operated by BE and Magnox Electric; specific responsibility within NII for new build, meeting 30 July 2003
- Peter Storey, Head of Research of the Nuclear Safety Directorate within the HSE, member of the DTI Nuclear Skills Group, meeting 30 July 2003

Government:

- Clive Smith, Nuclear Skills Group, DTI, meeting 8 August 2003
- Stephen Spivey, Director of Legislation Team, Nuclear and Coal Liabilities Unit, DTI, meeting 13 August 2003

Academic:

- Simon Franklin, Director of Reactor Operations & Safety, Imperial College Research Reactor in Silwood Park, meeting 11 June 2003
- Anthony Goddard, Professor of Environmental Safety, Imperial College, meeting 12 June 2003 and email exchange

- Robert Heathman, Associate Programme Manager for Engineering, Engineering and Physical Sciences Research Council (EPSRC), Email exchange
- Dr. Jürgen Knorr, Professor of Nuclear Reactor Technology, Technical University of Dresden, Germany, Email exchange
- Dr. William Nuttall, Course Director & Lecturer, Judge Institute of Management, Cambridge University, meeting 26 June 2003

Semi-Structured interviews with a small sample of interviewees, raise issues with reliability and bias of the information gathered (Saunders, Lewis and Thornhill 2003:252). It was felt that, in the light of background research undertaken, a sufficiently broad range of interviewees was selected to reveal the most important issues relevant for this chapter. However, given that a majority of the interviewees is likely to have a professional interest in the expansion of the nuclear industry, issues of bias remain. These will be discussed more closely in the discussion of the results for this part of the study in section 4.8.

A number of 'themes' were identified along which the interview was organised, but the interviewee was allowed to speak freely and depart from the structure where and when possible. These themes are shown in textbox 1 below:

<u>Textbox 1 – Topics for interviews on the UK nuclear skill base</u>

- specific and generic skills required in the nuclear clean-up sector
- specific and generic skills required in the nuclear reactor design and operation sector
- transferability of skills between these sectors
- nuclear research in the UK
- contribution of the NDA to nuclear research and training
- impact of projected skills shortage on the NII

The results of the interviews are presented in Chapter 4. Suggestions for further research following from the findings in this chapter are discussed in the conclusion in section 6.1.

2.2.2. Semi-Structured Interviews for Chapter 5 – Safety and Security in the light of recent terrorist attacks

Very little information is available in this area. One useful background document was the OCNS annual reports 2002 and subsequently 2003 (OCNS 2002, OCNS 2003). Discussions with a researcher from POST working on a related topic helped to identify first point of contacts which, through the 'snowball effect' lead to further sources of information. LexisNexis was used to research newspaper reporting on key events in recent history that related to the research topic. The focus was especially on the terrorist attacks of September 11, 2001 and their implications for nuclear power, subsequent anti-terror legislation in the UK and the publication of the Energy White Paper in 2003. Hansard was used to research parliamentary debates around the anti-terror legislation in 2001. In the light of this background research, the stakeholders identified for this part of the study were the nuclear industry, nuclear regulators, the two international atomic energy organisations IAEA and NEA and environmental non-governmental organisations (NGOs).

However, security considerations meant that in some cases interviews never materialised. In this respect the anti-terror legislation in the UK is worth noting: "Section 79 of the Anti-Terrorism, Crime and Security Act 2001 introduced a new offence for anyone to make an intentional or reckless disclosure of information that might prejudice the security of nuclear premises or material." (OCNS 2003:13)

Thus:

- Michael Buckland-Smith, director of civil nuclear security at OCNS, declined to contribute to this study and referred to public-domain publications by the OCNS
- Laurence Williams, HM chief inspector of nuclear installations similarly referred to public-domain literature from the NII

Furthermore, in a number of cases, it was impossible to receive an answer to a first letter of contact. This was in the case of the following:

- Alain Laurent, Director of Procurement, Electricité de France (EDF)
- Juergen Kupitz, Head of Nuclear Power Technology Section of the Division of Nuclear Power, IAEA
- Rachel Williams, nuclear campaigner, Friends of the Earth UK

Also, Greenpeace UK declined to offer any assistance in the study, quoting resource constraints as their reason. Consequently, those people that were able to contribute to this study were as follows:

<u>Nuclear Industry:</u>

- Richard Mayson, Technology Director for Reactor Systems, BNFL, meeting 26 June 2003
- Stephen Floyd, Vice President Regulatory Affairs, US Nuclear Energy Institute (NEI), Letter 1 August 2003

<u>International Organisation</u>

- Dr. Ted Lazo, Head of Radiological Protection, NEA, emails: 20 June, 10 July 2003

Given this very small sample of stakeholders in the issue of the chapter and the inevitable bias this was likely to generate, it was decided to draw on grey literature produced by environmental NGOs and other sources to contrast the arguments. Secondly, it was decided to make the question of availability of information and security confidentiality itself an issue of the topic. In this respect, criteria for public acceptability of nuclear power were briefly reviewed A further contact, recommended by a researcher within POST, with knowledge and experience in public consultation processes and nuclear policy was established. Thus, a fifth category, previously not identified, was included.

<u>Research academic:</u>

- Dr. Jane Hunt, Research Associate, Institute for Environment, Philosophy and Public Policy, Lancaster University, meeting 25 July 2003

Inevitably, the results of such a process, as presented in chapter 5, can only be indicative at this stage. They leave, however, room for further research, a topic discussed in the conclusion in section 6.1.

Having summarized the methodology that was used in the course of the research for this study, the findings will now be presented. In the following chapter, the results of a literature review on the economics of nuclear power and the radioactive waste management issue are discussed.

Chapter 3 Economics and Waste – established issues

In the last chapter, the methodology for this study was outlined. As mentioned in section 2.1, the issues of economics and radioactive waste will be discussed by means of a literature survey. In the following, it is attempted to outline the key features of each topic as they relate to the initial research question of what it takes to keep the nuclear option open. This chapter will start with a brief historic background to nuclear power in Britain in section 3.1. Subsequently, it covers the economics of nuclear power in section 3.2., while section 3.3. addresses the radioactive waste management issue.

3.1. Historic background to nuclear power in the UK

Since the discovery of the nuclear chain reaction as a source of energy for electricity production, nuclear power has been hailed as a saviour for modern societies. At the time of the first nuclear reactor in Calder Hall going critical in 1956, *The Economist* declared that "nothing will be quite the same again" (Hall 1986:32), while the chairman of the US Atomic Energy Commission in 1954, Lewis L. Strauss, is on the record for stating that in the future, electricity from nuclear power will be "too cheap to meter"(cited in Heppenheimer 2002). Even after setbacks with the first series of Magnox reactors in Britain, the renewed efforts that were put into the development of the AGR nuclear power programme in the 1960s were welcomed as "the greatest breakthrough of all times…we have hit the jackpot with this." (Hall 1986:91) More on the contrary, the AGR programme turned out to become the "AGR disaster" (Hall 1986:91) with costs turning out to be "over twice the original estimate [in real terms]" and work on the first reactor finishing almost two decades after the programme started. Nevertheless, this series of new reactors did not stand in the way of commissioning the last reactor project in the UK – the PWR in Sizewell B which was approved in 1987 and became operational in 1995.

Consequently, the early enthusiastic comments stand in marked contrast to today's much more sceptic evaluations of the prospects of nuclear power. Following the privatisation of the electricity industry in 1989, the full costs of the past nuclear programmes became much more exposed. The former Prime Minister Margaret Thatcher (1993:685) stated that "as a result of the transparency required by privatisation we […] became the first country in the world to investigate the full cost of nuclear power - and then to make proper financial provision for them" Thus, in 1989, the DTI declared a *de facto* five-year moratorium on new nuclear build, pending the outcome of a review in 1994 (Wakeham 1989). This review established the principle that new nuclear power plants should be built with private finance and in market competition rather than with state support (DTI 1994). This view was reconfirmed in a recent white paper on energy policy, where the DTI declared "we do not believe Government is equipped to decide the composition of the fuel mix. We prefer to create a market framework…" (DTI 2003a:11) and further "its current economics make new nuclear build an unattractive option and there are important issues of nuclear waste to be resolved … we do not, therefore, propose to support new nuclear build now." (DTI 2003a:44)

3.2. The Economics of nuclear Power

As outlined above, the costs of nuclear power were a recurrent theme of debate around nuclear power in the UK. This part will now focus on three particular aspects of nuclear economics: The components of nuclear costs, new nuclear reactor designs and policy in relation to new nuclear build.

In the first part, the concept of levelized unit costs (LUC) is introduced and those components that are part of nuclear LUC are identified. These are capital costs, operation and maintenance (O&M) costs, as well as back-end costs of decommissioning and waste management. Subsequently, BNFL/Westinghouse's assumptions of LUC for newly designed nuclear reactors are presented and critiqued. In conclusion, those fields where policy can have an impact on the nuclear option are outlined.

One aspect that will not be pursued in any detail here is the legacy of state support to the nuclear industry. There is an argument that challenges the nuclear cost assumptions on the basis that, in the past, various subsidies have been granted to nuclear power thus blurring its 'true' costs. Starting with the international convention to limit liability of nuclear power operators in the case of an accident, over research and development support to direct price subsidies in the form of the now-abolished NFFO, nuclear power has benefited throughout its lifetime from state support (Greenpeace 1994). This discussion, which would also need to look at subsidies to other forms of electricity generation, such as coal, is essentially backward-looking and would be beyond the scope of this study and will not be included here.

A useful starting point for discussing the economics is a look at the typical cost structure of a nuclear power plant. In order to get a comparison of electricity generation costs between different technologies, it is common to quote them in p/kWh or £/MWh (e.g. OECD/NEA 1998). These so-called levelized unit costs are calculated by dividing the NPV of the (expected) life time costs of one technology by the NPV of its (expected) life-time output. Individual cost components, such as capital costs, can be presented in this way. A further but less comprehensive measure of costs is overnight capital costs, given in £/kWe, which divides the total undiscounted capital costs by the rated output of the power plant. In the following, only levelised unit costs will be considered.

Historically, the bulk of the life-cycle costs of a typical nuclear reactor have been upfront investment costs. "Characteristically, some 60% to 70% of the per-kWh costs of a nuclear project are directly related to capital cost." (MacKerron 1992) Although new designs such as the AP1000 claim to have significantly reduced the material requirements and construction time, it is projected that they still account for between 50% and 60% of the LUC (BNFL 2002).

The other two major cost items are related to commercial operations and the so-called back-end of the fuel cycle, i.e. decommissioning and waste management costs. While costs related to commercial operations typically account for 40% to 50% of LUC with the new designs, waste management costs are relatively small. Financial risks related to capital costs, commercial operations and waste management costs are discussed below.

3.2.1. Capital Costs

As capital costs make up the main part of total levelized unit costs, the economics of nuclear power is especially sensible to changes in them. Factors influencing capital costs, either in absolute, or, more importantly, per kWh, are especially the discount rate, construction lead-time, reactor lifetime and load factor of the plant (MacKerron 2001).

In performing a sensitivity analysis, Pearson and Peña-Torres (2000) show how small changes in variables influencing capital costs can have a significant impact on the LUC. This is due to the large-scale investment that is needed upfront. Time and cost overruns in construction worsen the impact of the cost-revenue profile and the impact of the discount rate. For the payback time, the reactor lifetime and the load factor determine the amount of electricity that can actually be produced and thus the amount of revenue that can be generated. Using data from the DTI nuclear review (1994), a baseline case scenario produced a range of capital costs between 2.8 p/kWh and 5.2 p/kWh at a discount rate range from 10-15% and lifetime load factors between 75-80% (Pearson and Peña-Torres 2000). Though the cost basis for the actual figures is from older nuclear power plants, this study serves to illustrate the sensitivity of nuclear projects to variations of these key parameters. Similarly, Grimston and Beck (2002:65) showed, using data from OECD/NEA (1998), how a move from a 5% to a 10% discount rate increased total LUC of nuclear power by 50%. In contrast, for gas, LUC increased by only 10% and for coal by 30%. Textbox 2, below, gives an example where MacKerron (2000) demonstrates the effect on the capital cost structure of switching from low public sector discount rates to the higher market discount rates.

<u>Textbox 2: Example of the impact of discount rates</u>

"Examples of the strength of the discount rate effect can be seen in the case of nuclear power investment in the UK in the 1980s. The Sizewell B project appeared to be viable (positive net present value) at a 5% public sector discount rate and was approved on that basis in 1987. By 1989, the official rate had risen to 8% and the next project, Hinkley Point C, was at the margin of apparent viability (though with lower expected construction costs than Sizewell). By 1994, the nuclear utility Nuclear Electric was advised that the lowest possible discount rate for a nuclear project would be 11%, and at this rate, the proposed Sizewell C was a large loss-maker, though the construction costs were even lower than those expected at Hinkley Point C." (From: MacKerron 2000)

3.2.2. Operations Costs

Traditionally, the most important items that have been included under this heading were fuel costs and normal operations and maintenance. However, with the liberalisation of electricity markets, items influencing financial costs such as market risks and outages with their associated opportunity costs become important as well (Standard and Poor's 2003). The costs of defending nuclear power plants against terrorist attacks are discussed separately in chapter 5.

From an economic perspective, one aspect that makes nuclear power very attractive in principle is its low operating costs. Fuel, staff and maintenance costs are typically a small share of total LUC. Additionally, fuel prices have been less volatile historically than fossil fuel prices, which adds to the stability of this cost item. In its costs assumptions for the AP1000, BNFL assumes that all costs associated with fuel, staff, materials, insurance and grid connection together will be less than one third of total LUC (BNFL 2002).

However, the UK now operates a fully liberalised electricity market, where electricity is mainly sold through bilateral contracts between power generators and power supply companies. Nuclear power operators face competitive pressures to sell their electricity as cheaply as possible. In monopoly markets, long-term power purchasing contracts at fixed prices provided a stable environment for electricity from nuclear power. Moreover, unexpected cost increases could be passed on to consumers. Now, there are market risks in the form of price volatility that influence the time to recoup initial capital investment and to cover cash flow. They are included here as they either have to be hedged against and thus add to the marginal costs of a nuclear power generation operator or they are a real cost when revenue is lower than marginal costs, which impacts on cash flow. The insufficient hedging against market risks of British Energy has frequently been cited as one of the main reasons for its financial difficulties (The Independent 2002). Secondly, contracts will normally include clauses for replacement power should an operator be unable to deliver the agreed electricity output. Standard and Poor (2003:6) notes in this respect: "Given nuclear power's vulnerability to rare, but extended forced outages, replacement power costs for 1000 – 2000 MW of base load power could be considerable, which would factor into credit risks." Again, an unplanned outage at its 'Torness' nuclear power plants was a reason cited for British Energy's deteriorating financial position in 2002.

3.2.3. Back-end costs

As illustrated in table 1 below, back-end costs have a very small share of total LUC. This is due to the long lifetime of a nuclear reactor (for new reactors the operating lifetime is projected to be 60 years) and the fact that provisions for waste-related costs can be accumulated over that time. Even with a low discount rate of 3.5%, a cost, say, 50 years from now has only a present value of 18% of its undiscounted value (PIU 2002b); so although the absolute value of waste management costs is high – as observed by the liabilities the Nuclear Decommissioning Agency (NDA) in the UK had to pick up (see i.e. DTI 2003b) – their NPV over a project lifetime of a plant is rather small.

In the US, it is government policy to charge 0.1 $c per kWh to cover the life-time costs of a final repository such as the proposed Yucca Mountain site. At current estimates in a business-as-usual model, total revenue under this scheme will be in the region of US$38bn. This number has been criticised as insufficient. Loux (Nevada Nuclear Waste Project Office) suggests that, if Yucca Mountain would be selected as the final repository site in the USA, the full life-time costs of this site would be in the region of $100 billion. This underlines a point made earlier. If the higher cost estimates were included at the beginning of a nuclear project, the impact would be less severe as the higher costs are included in the project calculation, i.e. they would be foreseen. Levelised costs would still rise from the current 0.1 $c to approximately 0.36 $c per kWh which is a more than threefold increase (full calculation in appendix 3). However, the change would be much more pronounced if costs projections were revised upwards only at a later stage of the lifetime of a nuclear plant. In an example where costs were revised upwards half-way through the lifetime of a nuclear plant, the levy would rise from 0.1$c/kWh to 0.59$c/kWh to cover the shortfall, a more than fivefold increase which furthermore is unexpected and thus unaccounted for. In a liberalised market, as the UK is, there is no longer a captive consumer market to which these cost increases could be passed on. Hence, these costs constitute another market risk which could threaten the viability of a nuclear power plant at a later stage in its project lifetime.

The recent intervention of the British government in the case of British Energy plc (BE), a nuclear power generation company that faced bankruptcy in 2002, could potentially add to this argument. As a recent letter by the European Commission (2003) to the UK government outlines, part of the rescue package for BE might be incompatible with EU state aid regulation. One aspect of this rescue package included the government covering all liabilities that BE otherwise would have had to provide for. This raises the question of moral hazard of the industry and time inconsistent action on the side of the government. In the actual case of BE, one justification for the intervention is, that, since the liabilities originally accumulated at a time when the assets BE now owns were still in public ownership, it is the government's responsibility to ensure their safe disposal. But the official reasoning on the government side goes further than this and makes its case more generally. It argues that it has to accept responsibility for nuclear liabilities in any case, since it is in the public interest to ensure the safe handling of these potentially very harmful substances.

In a statement to Parliament on 28/11/02, Patricia Hewitt, the Secretary of State for Trade and Industry, argued: "I offered that loan because it was the best way of securing the safety of the nuclear power stations […]" and further: "Let me stress, Mr Speaker, that if British Energy were to go into administration all its nuclear liabilities would fall to Government. We cannot just walk away from them; no responsible government would. This is the reason why the situation with British Energy is different from any other generator." This is echoed by a subsequent argument in the House of Commons by the Energy Minister Brian Wilson on 06/02/03. In response to a question, which asked why the government would not "rush to the House to ask for authority to buy […] shares […] when other companies go into administration", he stated: "Because nuclear is different… Other companies, even other power companies, can go to the wall. Though it is sad when jobs are lost, one can turn the key and walk away if nobody buys them, and that is the end of the story. In nuclear power generation that is the one thing that cannot be done. There must be an owner. "

There is of course no guarantee that a government which assumes financial responsibility for nuclear power companies continues the operation of their plants and does not simply close them down. However, the fact alone that the government intervened in this case might be exploited in the future. As suggested by Mrs Hewitt, any "responsible government" would bail out a nuclear power company in case of financial difficulties because of the "different" type of assets and liabilities that are part of the nuclear industry. This fundamental position raises the question of the true extent to which nuclear power can be operated in a market framework with private investors. Statements of the kind outlined above could give incentives to investors to exploit government commitment to act accordingly. In economic theory, the cases of moral hazard and time inconsistency are well-established concepts[3].

[3] Further reference to moral hazard in Barr (1998), for time inconsistency see Blanchard (2000)

Applied to the specific case of nuclear back-end costs, it could be argued that there is an incentive for nuclear power station operators to either under-provide for back-end costs or to implement a riskier business plan than it would if normal market rules prevailed. The government's action over BE has sent a strong signal to potential investors in relation to this matter. Although it is official policy that any investment into new nuclear power stations would have to come from private investors, and that new reactors would have to operate in a competitive market framework, it now seems evident that once new power stations were operating, there would be an implicit guarantee from the government to safeguard nuclear liabilities regardless of the financial position of the owner. In this case there would be the incentive for moral hazard due to expected time inconsistency in government behaviour which would constitute a significant market distortion[4].

3.2.4. Overall Risks

Except for the last point discussed, the various factors mentioned taken together constitute a major financial risk to potential investors into new nuclear power plants. The new generation of nuclear power plants currently proposed by the industry has not yet been built anywhere. Thus, the purported shortened construction schedules, lower capital costs and improved operational performance remain unproven.

Furthermore, the past record is not favourable. "The history of nuclear construction has not been a felicitous one." (Grimston and Beck 2002:73) Overruns in cost and time were frequent, and this problem was not confined to the UK in the past (MacKerron 1992). Historically, inefficient operation especially with low load factors further worsened the economics. Thus, past experience with nuclear projects is a weak basis to support current cost projections presented by the nuclear companies. However, recent experience with nuclear power plant construction in South East Asia shows that they can be built to cost and time (Grimston and Beck 2002).

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[4] At the time of writing, the European Commission was still considering whether the UK government's rescue package for BE violated EU competition rules. "The Commission doubts that it can be held that the restructuring aid has no effect on BE's competitors." (European Commission 2003:37)

3.2.5. New proposed Reactor designs and their cost assumptions[5]

The general discussion so far will now be put into the context of the new design of nuclear power stations. British Energy (2001) in its submission for PIU (2002a) named two nuclear designs which it considered an option for near-term new build in the UK. These were the BNFL/Westinghouse AP 1000 and the AECL NG CANDU reactor. Of those two, only the former has explicit cost estimates available, thus the focus subsequently will be on the AP1000.

Table 1 below presents the cost estimates that BNFL assumes for their AP1000 plant if built in the UK[6] (BNFL 2002):

Table 1– AP1000 cost figures	AP1000 – 1st plant	AP1000 - 4th plant
Capital Cost	1.82p/kWh	1.11p/kWh
Operation and Maintenance	0.69p/kWh	0.69p/kWh
Fuel	0.3p/kWh	0.3p/kWh
Spent Fuel management and Decommissioning	0.14p/kWh	0.14p/kWh
Total:	**2.95p/kWh**	**2.24p/kWh**

As can be seen from table 1, BNFL expects the LUC of the first AP1000 to be 2.95p/kwh. Through the simplified design and modular construction significant economies of scale are expected so that the LUC would fall to 2.24p/kWh for the fourth and consecutive plants. This is reflected in the capital cost item, which is suggested to fall from 1.82p/kWh for the first plant to 1.11p/kWh by the time the fourth plant is constructed. In the following paragraphs, these assumptions are critiqued from a variety of perspectives.

[5] Following the completion of this report, it was possible to obtain a very detailed discussion of cost estimates for the NG CANDU reactor by AECL (‘ACR 700’). However, this information is not retrospectively included in this section; AECL expects the ACR 700 to have LUC within a range of 1.6 – 2-5 p/kWh. It is likely, in terms of the conclusion of this section, that while these figures, if attained, would circumvent the necessity for some of the economic instruments discussed in section 3.2.6, however, it is likely that issues in the planning system would still persist.

[6] For a discussion of the technical features of the AP1000, see Cummins and Mayson (2002), “Westinghouse AP1000 Advanced Passive Plant: Design Features and Benefits”, Paper presented to the European Nuclear Conference (ENC) 2002, Lille, France, 9 October

Ion, Bruschi and Matzie (2001) outline the assumptions underlying the above calculations as follows: A 20-year plant lifetime, 8% post-tax discount rate, 93% plant lifetime availability and fuel and O&M performance similar to the top quartile of Westinghouse customers. They also point out that the low-end projections of BNFL assume the building of AP1000 units on existing nuclear sites with their current infrastructure retained, and with improved regulatory and planning processes in place.

In contrast to the above assumptions, Pfaffenbarger and Bertel (1998:1) state the base assumptions for comparing electricity generating technologies that were used in a comparative study by the OECD as follows: 5% and 10% discount rates and 75% annual load factor. However, they also stress that "5% discount rates is below what most utilities or plant investors in OECD countries are likely to use when evaluating different plant investments (1998:7)." The point here is that a 5% discount rate is only realistic when it is used by the public sector. In the UK, however, investment would have to come from private investors. Pearson and Peña-Torres (2000) quote a discount rate between 10% and 15% as realistic for new nuclear build in the UK.

Khatib (1997) points to the different assumptions underlying public sector and private sector discount rates. While it is assumed that private investors are 'impatient' and want a relatively quick return on their investment, governments assume a 'social' time preference, taking into account longer-term societal benefits. This leads to a lower discount rate demanded. Furthermore, the central role of performing sensitivity analyses in project appraisals for key parameters, such as the discount rate, is underlined.

PIU (2002b) criticise the cost estimates of BNFL as optimistic and presenting "asymmetric risks". Varying some of the assumptions underlying BNFL's estimates, they produced a range of 2.5p/kWh to 4p/kWh as a realistic range of likely future nuclear costs.

In summary, especially taking into account that BNFL's assumptions on discount rate and plant availability are significantly more optimistic than what is considered standard assumptions in international accounting for electricity projects, it is likely that BNFL's figures represent the optimistic end of the expected cost spectrum. But the key issue underlying this is again that there is significant uncertainty in the estimates on nuclear costs. Mayson (BNFL) argues that the situation presents a classic catch-22 situation as the cost estimates cannot be proven unless a new nuclear plant is built, but private capital will be hard to come about before there is more certainty of the lower costs. This situation is made worse by the fact that the lower end of the cost projections would only come about as the result of a series programme of new build, involving at least four reactors with concurrent capital requirements of several billion pounds.

3.2.6. Implications for keeping the nuclear option open

This discussion has some implications for the initial research question. This sub-section outlines what policies are currently discussed and might be required in the UK in order to keep the nuclear option open.

There are unique first-of-a-kind risks for an investor providing the capital for new build that might require policy intervention of some kind. Mayson (BNFL) points to a bill currently in the US senate (Energy Policy Act 2003, Senate Version (S.) 14) that could provide power purchase agreements or loan guarantees of up to 50% of capital costs for the first new nuclear power stations to be built in the US. Holt and Parker (2003) estimate that the maximum federal exposure of these provisions would be in the range of US$14 - $16bn in 2002 Dollars, spread over about six to seven nuclear reactors with a total of no more than 8,400 MWe installed. They also quote a US Congressional Budget Office estimate, dating May 7, 2003, which predicts "that the risk of default [for the loan guarantees] would be greater than 50%." (Holt and Parker 2003:2) A Standard and Poor's Rating report (2003:10) furthermore questions whether the proposed loan guarantees would actually be enough to make nuclear power competitive with CCGT or coal plants in the USA: "An Energy Bill that covers advanced design nuclear plant construction risk may go a long way toward allaying those concerns, but if operational and decommissioning risks remain uncovered, look for lenders to sit this opportunity out."

It remains to be analysed in detail to what extent the US situation is applicable to the UK. Still, it seems likely that the economics of nuclear power are currently a big obstacle to keeping the nuclear option open. As mentioned before, the new reactor designs have never been built before, "the risks tend to be asymmetrical with an enormous downside bias against credit providers and little or no upside" (Standard and Poor's 2003:2) and the unit size is large with little scope to vary output according to market requirements.

In spite of the fact that, from a purely economic viewpoint, the government does not have to take immediate action to keep the nuclear option open, it seems likely that it will have to act once decisions about new build have been taken. It would then have to alter one or more of the conditions underlying the risk profile described above in favour of nuclear power. Here, the options are numerous in principle. Firstly, it could introduce market measures that honour the CO_2-free status of nuclear power, i.e. exemption from the current climate change levy, a new carbon tax and/or the upcoming EU carbon trading agreement. It could also decide to introduce specific measures to improve the competitiveness of nuclear power, such as those currently debated in the US, i.e. loan guarantees or power purchase agreements. Lastly, it could decide to change or abandon the market rules in principle, thus reducing the generally unfavourable risks that the liberalised market introduced upon nuclear power. Furthermore, changes to the planning and licensing system of nuclear power plants could significantly reduce the lead-time and construction costs, although the trade-off here is likely to be with reduced public acceptability.

Whatever measures or combination of measures would be taken, they seem likely to be instrumental in keeping open the option on currently available nuclear reactor technology. Whether they would in all cases be approved under EU state aid regulation cannot be discussed within the scope of this study. Certainly, the BE case currently under investigation provides a precedent in this respect. Furthermore, future technologies could change the above assumptions and will be discussed in the conclusion in section 6.2.

3.3. Radioactive Waste Management

A second area of recurrent debate in nuclear policy is that of radioactive waste management. The issues surrounding this topic will now be outlined in this section. The purpose here is twofold. It will firstly summarize the technical issues involved and describe the different options for a final waste route available. Secondly, it will present the current status of the radioactive waste management debate and recent policy developments. In this way, the key issues relating to the conditions that are required to keep the nuclear option open are highlighted and will be summarised at the end of the chapter.

The wastes considered here are solid Low-Level Waste (LLW), intermediate-level waste (ILW) and high-level waste (HLW). Definitions for each can be found in Appendix 2. This section will not include a discussion of reprocessing as it is not considered essential to keep the nuclear option open for the following reasons. The British reprocessing facility in Sellafield was conceived in the early 1970s when it was thought that nuclear power would expand rapidly and uranium as its fuel source would be in short supply and thus both costly and hard to acquire. Both of these assumptions proved to be false, yet the UK reprocessing facilities were built and BNFL finally started operations in 1994. It is now broadly accepted that it represents a more expensive way of handling spent fuel than simply storing it[7]. Furthermore, there are important issues around the waste discharge from Sellafield and more importantly, about the actual reprocessing technology itself. As it is an option in waste handling, but associated with economic, environmental and technical difficulties, it is not considered to play a major role in the future of nuclear power in Britain[8].

3.3.1. The Current Stock of radioactive waste in the UK

The total volume of stocks of LLW, ILW and HLW can be seen in Table 2. The first row gives the current estimate as of 1 April 2001. The second row gives an estimate of total future waste arisings after conditioning[9] in a business as usual scenario with no new nuclear build.

	1 April 2001	Total future waste estimate
LLW	14,700 m^3 (17,800 t)	1.5m m^3
ILW	75,400 m^3 (90,400 t)	163,000 m^3
HLW	1960 m^3 (3290 t)	750 m^3
Total	92,100 m^3 (111,000 tonnes)	1.7m m^3

Table 2: Current and Future Stocks of UK radioactive waste (Nirex and Defra 2001)

[7] One of the reasons for BE's recent financial difficulties were reported as being the expensive contracts on reprocessing it had to fulfil with BNFL. Grimston estimates that storing spent fuel after usage is cheaper by a factor six than reprocessing.
[8] Indeed, at the time of writing, newspaper reports speculate about an early closure of the reprocessing plant at Sellafield, due to a lack of new contracts for the plant (The Guardian 2003a)
[9] Conditioning refers to the process in which wastes are solidified. In the case of LLW and ILW this is typically done by mixing it with concrete, while liquid HLW is vitrified into glass blocks that can be put into stainless steel containers.

66% of the ILW and 90% of the HLW is stored at Sellafield. This means that the majority of current UK radioactive waste as measured by volume is stored there. Also, measured in terabecquerels, approximately 87% of the radioactivity in all wastes in stock in the 2001 inventory were stored there. (Nirex and Defra 2001)

Solid LLW is mostly disposed of at the national disposal site in Drigg. It is compacted in drums which are placed in large boxes and then encased within concrete.
Solid ILW can be conditioned with concrete and then filled in stainless steel drums to provide a physical barrier against the escape of radioactivity. In 2001, 11,200 m^3 of ILW in 21,600 packages were stored in this way in Sellafield.
Liquid HLW which arises from the reprocessing of spent fuel can be vitrified within stainless steel canisters. In Sellafield, 340 m^3 of HLW in 2280 packages were stored in this way at the last count. Thus, 1620 m^3 of HLW in liquid form still await vitrification. (Nirex and Defra 2001)

3.3.2. Frequently cited options for radioactive waste management

Frequently cited options for radioactive waste management are:

- Surface or near surface Storage
  This would essentially mean carrying on doing what is done with most of the UK's radioactive waste at the moment. It would require the repackaging of waste and the rebuilding of stores approximately every 100 years. It would require ongoing monitoring and for the waste to be retrievable if necessary. Hence, options would be kept open as to what is ultimately done with the waste. This would be attractive should new methods to render the waste less harmful or for conditioning and storing it more safely be found. However, it also requires stable societies that can live with this type of waste being stored above or near the surface. If stored above ground, it leaves the waste exposed to terrorist attacks and other surface risks. (Nirex 2002) It also leaves a

‘burden’ for future generations to manage. There is an argument that this generation (that has benefited from nuclear energy) should deal with the waste in a way that does not impose a burden on future generations.

- Disposal in a deep underground repository/phased disposal

  These are two variations of the same theme. Wastes could be stored in a specially designed repository many hundred metres under the ground. Criteria exist to rank the suitability of the varying geology against preferred characteristics. In the phased disposal concept, the repository would initially only be used as a store which could be monitored and where the waste remains retrievable. This would allow for additional data collection which could further validate the suitability or otherwise of the chosen site. Ultimately, if deemed acceptable, the repository would be sealed off with the goal to keep away radioactivity from the living environment. Here, the benefit is that wastes would be ‘passively’ safe, i.e. not requiring active management by future generations. The disadvantage with the immediate disposal option is that it would be hard to retrieve the waste should a better option become available or there were unforeseen problems with the site. This is mitigated to some extend with the phased concept which gives more flexibility and leaves future generations with the options still open. (Nirex 2002)

- Disposal at sea/sub seabed disposal/ disposal at subduction zones

  Although disposal at sea was carried out for some time, all the above options are now prohibited by international conventions (i.e. London Dumping Convention) (Nirex 2002).

- Disposal in Space

  Sending waste out beyond the earth’s gravitational field would permanently remove it from the living environment. The large volumes and weights of waste would make this a very expensive option and would require a great number of launches. This in turn would increase the likelihood of an accident which would have “widespread consequences” (Nirex 2002).

- Partitioning and Transmutation

  This process could in theory remove or reduce the radioactivity of some waste materials. "It would involve chemically separating radionuclides (partitioning) and bombarding them with protons or neutrons in a nuclear reactor or particle accelerator (transmutation)." However, this concept has yet to be demonstrated on a large scale and still a lot of research is needed to overcome technical difficulties. (Nirex 2002)

3.3.3. Current Policy developments

The closest that Britain ever got to a final waste disposal route was the application by Nirex to build a rock characterisation facility (RCF) near Sellafield to investigate the possibility of building a final waste repository there. Following a public inquiry, this was rejected in 1997.

Subsequently, in a 2001 White Paper, Defra proposed a comprehensive review of all disposal options and called for a "national debate" on what should be done with radioactive waste. The government is in the process of setting up a Committee on Radioactive Waste Management (CoRWM) to conduct this debate. Nirex is not currently carrying out any site specific research. Its focus is currently on advising companies like BNFL on conditioning and packaging waste, maintaining an inventory of radioactive wastes in the UK and refining their models for a phased disposal concept. Nirex believes that phased disposal is a viable option for long-term management of radioactive waste, however it is currently reviewing its packaging advice as to ensure that other options are not foreclosed. Whilst phased disposal is Nirex's preferred option it recognizes that the consultation process needs to consider all options. (McKirdy, Nirex)

It has been argued that the problems with the RCF in Sellafield can be traced back more to political issues[10] than engineering concerns (Mayson, BNFL). This cannot be upheld entirely since even the final report of the inspector of the RCF enquiry criticised "the scientific uncertainties and technical deficiencies" and especially the site selection process (POST 1997:50). Still, even if these problems were overcome, Nirex has now fundamentally accepted that a process needs to be found which arrives at a waste management option in which the public has confidence. To this effect, Nirex underwent and is still undergoing fundamental

[10] 1997 was an election year, there was an apparent lack of public trust in Nirex, and Friends of the Earth and Greenpeace were actively campaigning against the RCF (POST 1997).

change. In principle, Nirex now embraces the notions of openness and transparency in decision-making, demonstrating this through its ‘stakeholder involvement programme’.

Furthermore, it fully accepts the current government policy to re-open the consultation process on which waste disposal route should ultimately be chosen (McKirdy, Nirex). More specifically, it was initially proposed by Nirex and it is now undertaken by the government to make Nirex independent of the nuclear industry. This is seen as a vital step to demonstrate Nirex’s independence in decision-making from questions on nuclear power and should thus serve to increase the public’s trust in the validity of Nirex work. It was set up and is still owned by what is now BNFL, Magnox Electric and British Energy, although further shareholders include the DTI and the UKAEA. However, Defra announced on 16 July 2003 that Nirex should be made independent of the industry and will announce, after shareholder consultation, by “autumn 2003” the exact way forward.

3.3.4. Evaluation of the steps taken

These steps are firstly important because they address some issues that were of concern for groups opposing a repository. Greenpeace (2002:5) states that “the only way to ‘solve’ the problem of nuclear waste is to not produce it in the first place.” It feared that a solution to radioactive waste of any kind would allow a continuous expansion of nuclear power. Given Nirex’s ownership structure it was expected to be under pressure to deliver and thus biased as to the best and safest solution to radioactive waste. Nirex now is neutral on the issue of new nuclear build. This is because radioactive waste exists already and a solution for its long-term management is needed regardless of future nuclear energy decisions (McKirdy, Nirex).

Secondly, these developments echo to some extent recent contributions from public consultation theory. Grove-White (2000) criticised the prevailing “expert culture” (p.2) and that the only official radioactive waste strategy was one of a “top-down scientific case” (p.5). In this context, Nirex was seen as a creature of the nuclear industry and thus viewed with deep suspicion. Consequently, he argues that “…reconfiguration of the company [Nirex] will need to incorporate a formal recognition that radioactive waste management should in future be institutionally independent of the future of nuclear power.” (p.9)

Similarly, the proceedings from a NEA/Forum in Stakeholder Confidence (FSC) workshop (2002) concluded that "confidence and trust in the regulatory body and the implementers is crucial" and "differences between risk perception by experts and lay people have to be understood and public concerns need to be taken into account."

The US National Research Council (2001:4) recommended that "national HLW programs should expand their efforts beyond technical project development and implement processes that involve the public in decisions to assure safety and security" whereby "for both scientific and societal reasons, national programs should proceed in a phased or stepwise manner, supported by dialogue and analysis" (p.5).

3.3.5. Implications for the Nuclear Option

These considerations have a bearing on the question of keeping the nuclear option open. It has been repeatedly argued that without a 'solution' to the nuclear waste 'problem' there can be no future for nuclear power. In 1976, the influential 'Flowers report' from the Royal Commission on Environmental Pollution (RCEP 1976:204) argued that "there should be no commitment to a large programme of nuclear fission power until it has been demonstrated beyond reasonable doubt that a method exists to ensure the safe containment of long lived, highly radioactive waste for the indefinite future". The DTI Energy White Paper (2003a:12) states that "…there are […] important issues of nuclear waste to be resolved" while the recent coalition agreement of the Scottish Executive maintains that "we will not support the further development of nuclear power stations while waste management issues remain unresolved" (Scottish Executive 2003:9). Also, the European Commission (2002) found in a pan-European poll on energy issues, that greater public acceptance of nuclear power might be gained if a solution to nuclear waste can be found.

Thus, a key question is the timeframe in which an acceptable management option can be found. Here, the process laid out in the White Paper "Managing Radioactive Waste Safely" (Defra 2001) provides a broad indication. According to this timetable, the aim is to agree upon a waste disposal route by 2007, but it is stressed that "… the process for identifying and implementing a strategy for managing radioactive wastes must not be rushed" (2001:62). It will therefore remain to be seen whether the government can finish its consultation process by 2007 and that this, indeed, is capable of delivering a strategy for radioactive waste management that is broadly acceptable. Still, even when this general strategy is decided, it will take time before a specific waste facility can be surveyed, selected and finally constructed. Hence, Nirex assumes for planning purposes that a repository would not be opened before 2040. Even if it is assumed that with a decision in principle on nuclear waste found by 2007, nuclear power will get a green light, the subsequent process of a new nuclear energy white paper, site selection, public enquiry and actual construction will mean that the very earliest, a new nuclear power station could go online around 2020 (MacKerron, NERA). This seriously puts into doubt whether nuclear power can be considered a short-term investment option in energy policy terms.

In conclusion, what action is required in order to keep the nuclear option open? It could be argued that since the question of nuclear power and nuclear waste disposal should be separated in any case, the discussion on waste management does not have an impact on the nuclear option. Mayson (BNFL) points out that, on the assumption that a programme of ten new AP1000 reactors would be built, the total new life-time waste arising would be about 10% of the total existing legacy waste. Furthermore, the fuel rods would be designed in such a way that it would be known exactly how to dispose of them, which is in contrast to some of the legacy waste where the exact composition is unknown.

However, in the light of the discussion presented in this section it seems that arguments about public acceptability and trust play a major role in this part of the general debate on nuclear power and that disaggregating radioactive waste from nuclear power in the public's mind may not be readily achieved. A recent University of East Anglia and Mori risk survey asked people about the importance of five different scientific risks relative to other personal and societal issues[11] (quoted in Poortinga and Pidgeon 2003:22). Despite six years since the issue of radioactive waste was last in the spotlight in the course of the RCF enquiry, it ranked on top of the other four scientific risks investigated in terms of its importance, and just between terrorism and the economy relative to the other issues mentioned. Similarly, a European-wide survey found great public concern about radioactive waste and distrust towards the nuclear

[11] The risks investigated in this study were: Climate Change, Radiation from Mobile Phones, Genetically Modified Food, Genetic Testing and Radioactive Waste

industry to deliver a solution (European Commission 2002). Should the government want to keep nuclear power as a short-term option, it would have to invest significant political capital in decoupling the issue of radioactive waste from nuclear power. Those attempts would likely be met with deep suspicion. Alternatively, it would have to shorten significantly the consultation process outlined by Defra (2001). This, however, would jeopardize the effectiveness of the process in principle and its influence on the general strategy of finding a waste management option in an open and transparent way which would carry public trust and support.

3.4. Summary

This chapter summarized by means of a literature review the key aspects of the economics and waste management issues that could influence the nuclear option in the UK. In section 3.2. it was concluded that although the findings did not necessitate any immediate action by the government, policy intervention of some type would be necessary once a new nuclear build programme started. Section 3.3. highlighted the importance of the timetable to find a publicly acceptable radioactive waste management strategy for the nuclear option. Given the current policy environment, it seems imperative to make significant progress in this area before a new nuclear programme, especially of the scope contemplated by i.e. BE (2001), could proceed. With these issues as a background in mind, chapter 4 will now analyse the UK nuclear skill base and its role in keeping the nuclear option open.

Chapter 4 The UK Skill and Knowledge Base

The last chapter summarized how the issues of economics and radioactive waste raise a number of concerns about the feasibility of new nuclear build in the UK. In this chapter, it will now be analysed how the changing UK nuclear skill base influences the nuclear option.

Taking the DTI nuclear skills study (DTI 2002 – subsequently called NSS) as a starting point to formulate the questions for the subsequent interviews, the areas of interest were narrowed down to the following points: Firstly, it is attempted to specify exactly those skills that are relevant to the nuclear option and in what way they might be provided for. Secondly, the area of nuclear research is discussed and its contribution to the nuclear option is examined. Thirdly, the roles of the Nuclear Decommissioning Agency (NDA) and the Nuclear Installations Inspectorate (NII) are analysed separately. In the last section, a comparison will be provided with the situation in Germany, a country which has recently declared its wish to phase-out the use of nuclear power, thus closing the nuclear option *de iure*. The implications of a decision to opt-out of nuclear power, thus effectively closing the nuclear option, for the nuclear skill base of a country are briefly illuminated and it is asked how this could be compared to the situation in the UK.

As its outcome, this chapter aims to analyse where the projected nuclear skills shortage may constrain most seriously the nuclear option in the UK.

4.1. The DTI Nuclear Skills Study

Two key papers gave an important background to the NSS. Firstly OECD (2000) asked in its study "Nuclear Education and Training: *Cause for Concern?*" whether its member countries were prepared to educate the next generation of nuclear scientists and engineers. It argued that while the current situation was still stable, more had to be done to ensure future abilities to train and educate people in the nuclear sector. Secondly, HMT (2002:2) (consequently called 'The Roberts Review') pointed to a "disconnect between [a] strengthening demand for graduates (particularly in highly numerate subjects) on the one hand, and the declining

numbers of mathematics, engineering and physical science graduates on the other".
The NSS surveyed not only the skills requirements in the nuclear power sector but also the health and military sectors. As this study focuses on the 'nuclear option' in relation to energy policy, only those sections that relate to the nuclear power industry will be reviewed.

While the NSS identified an immediate shortage of people with radiological skills in the health sector, it noted that the nuclear power sector does not have an immediate overall shortage. Assuming no new nuclear build, an aggregate forecast for the defence, power, fuel and clean-up sectors estimated a future demand of 15,500 graduates over the next 15 years and a further 7,850 people with skilled trade skills (p.8). The 15,500 graduates required by the defence, power, fuel, and clean-up sub-sectors over the next 15 years equate to approximately 1,000 graduates per year. Of these, 700 are replacements for retirements and 300 are a response to growth of nuclear clean-up (p.69). Furthermore, it is noted that in the particular area of nuclear power plant operations, because of plant closures, there is actually a decline in the number of employees needed. "The planned closure programme will result in a contraction of the sub-sector, which may counter the recruitment needs to replace retirements to some extents" (p. 68). Overall, it is projected, net of retirements, that, with no nuclear build, there will be a surplus of 1850 employees in this sector over the next 15 years.

A particular problem is seen in the age profile of the NII, which is significantly skewed towards the age band of 45 to 55-year olds, and where retirement will become a more pronounced problem than in the industry in general.

In relation to research, the NSS (p.19) notes, that "increasingly the funding of education and research is from diverse sources, which can result in conflicting demands on providers of learning pathways. The sector requires a coordinated strategy that balances the needs of employers, the requirements of academia and Government funding criteria, which should include collaboration between those organisations that fund research." Furthermore, the uncertain outlook on new nuclear build in the UK is mentioned as a reason for the increasing difficulty in attracting students into nuclear research (p.61).

A number of suggestions were made in order to safeguard the ability of the sector to recruit the right skills. The first factor is the "general promotion of the skill sector". Mirroring the

‘Roberts Review’ the NSS recognized that engineering and physical sciences are unpopular fields of study and unpopular career choices for young people. Beyond this, the NSS found that nuclear and radiological technologies are unpopular choices in this unpopular field. To address this issue, strategic recommendations were made. These included better coordination of the activities of stakeholders in the sector, inclusion in the national curriculum of nuclear content and a general “underpinning of essential learning pathways” (p.4). Additionally, there are a host of specific recommendations which would be beyond the scope of this paper to review in full length.

In summary, the NSS provided a comprehensive overview of the state of the nuclear skill base in the UK. However, information that related especially to the nuclear option in the UK was often aggregated with other more general information, thus making it difficult to extract those aspects that were most relevant. For example, there were conflicting signals as to the number of graduates that were needed in the industry, where on the one hand a recruitment need of about 15,000 graduates was identified, while on the other hand there was expected to be a net surplus in people with reactor operations skills, due to the expected closures of nuclear power plants. Hence, before interviewing stakeholders, more detailed investigation into the state of the different actors in the UK was undertaken. The results of this will be presented in the next section, focusing on the state of the industry, the research bodies, the NDA and the NII.

4.2. Current State of key actors

4.2.1. The nuclear Industry

One way in which nuclear skills can be conceptualised is that of ‘overhead costs’. The overhead of an industry can be described as the essential infrastructure around an industry supporting the ongoing operation or continuous provision of services. One such overhead is the skill base that the industry can draw on. It has to be maintained, developed and adapted according to changing demands from those sides that are in demand of the skills.

This is an important point as the nuclear industry at the moment is experiencing potentially large structural changes. The outlook for new nuclear build is uncertain at the moment and, as discussed in section 3.2., in the absence of clear government support, it is uncertain when there might be firm new orders on the horizon again. In contrast, there is a new statutory market developing in nuclear decommissioning and clean-up, forecasted to start in 2005. Foreshadowed in the DTI "draft nuclear sites and radioactive substances bill"(2003b), it is estimated to be worth at least £48bn over a very substantial timeframe.

There are two big nuclear energy companies in the UK. BNFL provides the whole nuclear supply chain, from nuclear fuel manufacturing to reprocessing and still operates the Magnox nuclear reactors. However, there are signs that BNFL is starting to specialise in two areas: nuclear reactor design (through its 'utilities service group'), and waste handling, nuclear decommissioning and clean-up of existing nuclear sites in the UK (through its 'government service group' - BNFL 2002). British Energy is a nuclear power plant operator, selling its electricity on the wholesale market. Having been on the verge of bankruptcy in August 2002, it had to reduce its portfolio to its core nuclear power plant assets in the UK, while its rescue plan and thus its future remains still unclear at the time of writing[12].

The present climate of structural change in the industry and uncertain future for new nuclear power plant programmes makes it more difficult to predict what type and number of skills will be needed and thus how much has to be invested into education and training and where. Still, keeping in mind the points raised in chapter 3, it is clear that both nuclear reactor design and nuclear waste management would be important parts of the nuclear option in the UK. Thus, the shape and size of the nuclear skill base in the UK has to be examined more specifically. One question that was furthermore taken up in the interviews was whether there was an overlap of skills required in the areas of nuclear clean-up and reactor development and operation and to what extent skills acquired in one area might be transferred to the other.

In this context, another question that arises is the domestic provision for these skills. As MacKerron (NERA) remarked, the nuclear power industry is now essentially a global one, where companies like BNFL are involved in joint-venture projects for example in South-Africa with the pebble-bed modular reactor project. Thus, in principle, the skills and technology are available internationally, relatively independent of UK developments in this sector. In fact, the last nuclear reactor built in the UK was an American-designed pressurised water reactor. However, the problem of a potential nuclear skills shortage is not confined to

[12] According to Newspaper reports (The Guardian 2003b), the government set BE a deadline to finalise a restructuring plan by the end of September 2003 while the EC was still considering legal action against the government's rescue package in principle (EC 2003)

the UK, as the OECD report (2000) showed. Thus, there are likely to be limits to the extent to which the UK can rely on the international nuclear skills pool to keep the domestic nuclear option open.

4.2.2 Nuclear Research

However, apart from currently available designs, future reactor developments may play an important part for the nuclear option. British nuclear research is still at the cutting edge of many international developments. Thus, an important aspect is not just the provision of skilled people for nuclear operations now, but also the ability of the UK to contribute to future reactor developments. Here, the most important programme is the Generation IV international reactor research programme (Generation IV 2003).

For the purpose of this report, the Generation IV initiative is considered the most relevant, as it could potentially deliver important technological advances. As discussed in section 3.3., the waste management timetable in the UK has important bearings on the timetable for decisions about new nuclear build. In the most optimistic scenario outlined, the first new reactor could go online at around 2020, which, incidentally, is also the timeframe envisaged by the Generation IV programme to deliver the first new reactor designs that could be built on a commercial scale. Apart from this factor, the ‘Technology Roadmap’ for Generation IV highlights the research priorities as to deliver, among other things, “economic and safe” designs that “minimise the arisings of new radioactive waste” (DOE 2002:6).

The amount of public funding that has supported and is supporting nuclear research has been declining over recent years. In 1989/1990, the year of the privatisation of the electricity industry, nuclear research funded by the then Department of Energy amounted to £164m. In the year 2000/2001 this budget, now administered by the DTI, had shrunk to £17m and all of this expenditure was nuclear fusion related (DTI 2003c).

The focus of research activity are partnerships between the private sector and universities. BNFL has set up “university research alliances” (URA) with four universities, Manchester, Leeds, Sheffield and UMIST, in the specialist areas of radiochemistry, particle science and technology, waste immobilisation and materials respectively. These issues cut across virtually all of BNFL's operation and provide a critical mass of research that is relevant to BNFL's future operation. In the next five years, over £40m will be spent on these collaborations.

The Engineering and Physical Sciences Research Council (EPSRC) is currently neither involved in the Generation IV research project nor does it have its own specific nuclear research programme. Funding applications in nuclear research have to compete with applications from other research areas (Heathman, EPSRC). However, recently EPSRC has addressed this issue and is committed to establish a joint research council programme with the ESRC and the Natural Environment Research Council (NERC) to help underpin research in nuclear fission.

4.2.3. NDA

The draft "nuclear sites and radioactive substances bill" (DTI 2003b) outlines a remit for the soon-to-be-established NDA to undertake research where necessary to underpin its fundamental task of decommissioning and clean-up. "The NDA shall […] have the function, to the extent that it considers it appropriate to do so, - of carrying out research into matters relating to the decommissioning of nuclear installations, the cleaning-up of nuclear sites […], - educating and training persons about those matters." (p.3) This is also underlined in a separate draft memorandum of understanding between the NDA and the relevant regulatory bodies[13], which states that "given its long-term strategic role, the NDA will want to encourage and where necessary fund research into improved techniques and procedures for decommissioning and clean up. In developing its research strategy it will take account of programmes funded or managed by the relevant regulatory bodies." (DTI 2003b)

Noting the funding likely to be available to the NDA and given its central role in all matters related to nuclear clean-up and decommissioning, it will be specifically examined to what extent the NDA can contribute to alleviate some of the forecasted skills shortage. This is explored in section 4.5.

[13] In this context, the 'relevant regulatory bodies' were the Nuclear Installations Inspectorate (NII), the Environment Agency (EA), the Scottish Environmental Protection Agency (SEPA) and the Office of Civil Nuclear Security (OCNS)

4.2.4. NII

A last sector for investigation is the nuclear installations inspectorate (NII). It has to recruit its employees from the same skill pool as the nuclear industry. However, the NII does not recruit people straight from university. Apart from a superior academic record, several years of experience in the industry is one of the key pre-requisites to enter the inspectorate. This has to be seen in relation to the level of responsibility inspectors take on. NII inspectors grant and review licences to nuclear operators without which the industry would not be allowed to operate. If an inspector is not satisfied, for example, with the safety case of a nuclear power plant, it is in his or her power to ultimately shut down the plant. Yet this recruitment imperative leads to a particular problem, highlighted in the NSS, in that the age profile at the NII is automatically skewed towards older age groups since the starting age is typically above 35 years.

Another problem are the resources available to the NII to carry out pre-licensing reviews of new reactor designs. This task forms a first key stepping stone in the overall licensing process in the UK for nuclear reactors based on novel designs. It is not strictly a legal requirement but has become common practice in order to familiarise inspectors with new reactor design features and ensure confidence in the subsequent licensing process. Early in 2002, the CEOs of both BNFL and BE asked the NII to undertake a pre-licensing review of the BNFL AP1000. However, this application could not be fulfilled as the NII did not have enough staff to carry out such a review without compromising its existing work.

In the light of this discussion, it firstly has to be asked, to what extent the NII is able to recruit people without compromising the quality of work it provides. Secondly, and importantly for the initial research question, it will have to be examined to what extend the NII is able to carry out licensing studies for new reactor types – a key ingredient to any new build program and thus to the nuclear option in the UK.

4.2.5. Summary

In the light of the background research presented above, the following areas for investigation were identified:

- Section 4.3.
    - specific and generic skills required in the nuclear clean-up sector
    - specific and generic skills required in the nuclear reactor design and operation sector
    - transferability of skills between these sectors
- Section 4.4.
    - nuclear research in the UK
- Section 4.5.
    - contribution of the NDA to nuclear research and training
- Section 4.6.
    - impact of projected skills shortage on the nuclear regulator (NII)

The responses from the interviewees as presented in the next sections will be clustered around the above headlines. Consequently, section 4.7. will give a discussion of the skill sector in Germany while section 4.8. will discuss the overall findings from this chapter.

4.3. Specific and Generic Skill Requirements; Transferability of Skills

It has been repeatedly acknowledged that the current interest in the nuclear skills issue stems less from an increasing workload that is more difficult to master than from a general retirement wave in the nuclear industry. Haddon (NIA) stated that some member companies in the NIA had experienced difficulties in recruiting people for specific positions but that the number of cases so far has been small. In terms of actual work to do, there has actually been a shrinkage over recent years. For example, in 1990 more reactors in total were still operating and there were more people working on them, while Sizewell B was also under construction. Since then, the Sizewell B construction finished, a number of Magnox reactors retired and privatisation put competitive pressures on costs which led to redundancies in the reactor operating companies. British Energy now operates with a staff level that recently raised concerns with the regulator as to BE's ability to satisfy licensing conditions in this respect (see also HSE/NII 1999). Generally, though, Haddon (NIA) felt it was hard to specify exactly which jobs were hit most.

Ascroft-Hutton and Storey (NII) gave an evaluation of the skills which are generic and specific to each branch of the industry, and to what degree they might be transferable between each other. Among those that were considered generic, they thought important skills such as project management, hazards management, civil engineering, mechanical engineering, criticality, health physics, radioactive waste management, materials and corrosion. Smith (DTI) added to this safety case writing. Skills that were considered specific to nuclear reactor operation included reactor physics, accident analysis, fuel behaviour and stress analysis.

Howarth (BNFL) generally agreed that there were a number of jobs within the nuclear industry (power plant and fuel cycle) that only required general engineering or science skills plus additional experience "on the job". For example, general project management skills were now needed in a variety of areas and people with science backgrounds could adapt to these tasks. However, he stressed the importance of those jobs that only highly and specifically skilled people are able to do. As a case in point, physicists in reactor operations "have sometimes spent all their lives working in their field", and people could not just transfer and out of these jobs with a general skills set without a great deal of experience and in-depth technical knowledge. Overall, the right balance between those specialists and general scientists and engineers with industrial training was considered important.

Smith (IMechE) gave a similar evaluation. "The majority of engineering undertaken for the nuclear industry is just conventional engineering with a higher than normal emphasis on safety. There are, however, a small number of specialists (perhaps 200-300) who have experience in reactor design and operation which is specific to the nuclear industry; they are only distinguished by the experience they possess."

New recruits typically have few specific nuclear skills when they enter the nuclear industry. Richard Booth (2001) presented a questionnaire by the "young generation network" (YGN) of the British Nuclear Energy Society (BNES) which asked its members "have you had any formal nuclear education?" The majority of responses quoted vocational (30%) and undergraduate (27%) training as their sources of nuclear education, while the answers “postgraduate” and “none” actually scored the same number of responses (16%). The remaining 11% indicated school as their source of nuclear education. This is reflected by the typical routes through which people enter the industry. They normally either study for a natural science or engineering degree and then enter the industry at various stages throughout their university career (i.e. at BSc, MSc or doctoral level) or they enter the industry as apprentices and learn their skills first hand within the respective companies. It has been repeatedly stated that the companies actually prefer to undertake the specific training for the relevant tasks in the industry themselves. This commitment has been recognized by new recruits and the whole package of on-the-job training and career progression is stated as one of the main attractions to enter the industry by YGN members.

A factor relevant to this is the fact that there are very few specific professional qualifications that are essential to progress in the nuclear industry. As Smith (IMechE) mentioned, the majority of work in the nuclear industry is related to conventional engineering. Additional qualifications are often obtained in short courses and certificate courses which will be further discussed in section 4.4. below. Thus, a main distinguishing factor in the industry is the years of experience gained in industrial training “on the job”.

This can also be explained with safety requirements by the NII as part of the nuclear site license. This licence requires operators to employ “suitably qualified and experienced people” (SQEP) for safety critical jobs. Furthermore, operators have to demonstrate a succession management for these jobs so that operations never rely on one person alone being able to do it (Haddon). SQEP job descriptions are specified for individual plants and circumstances and safety cases are inspected regularly by the NII.

As to the transferability of skills between nuclear reactor operations and nuclear decommissioning, there was no overall consensus. Generally, there seemed to be a number of skills, as outlined earlier, which would be transferable between reactor operations and decommissioning. However, it was assumed that some of those skills would only be transferable one way, namely from reactor operations to decommissioning. In the case of Magnox reactor decommissioning this was due to the specific knowledge that current staff of the plant has, which can be used later in their decommissioning (Smith IMechE). Still, given adequate training at least the time to transfer between both sectors is likely to be short.

Within the NII, people will have to be re-allocated from inspecting operating nuclear reactors to inspecting nuclear decommissioning. Thus, the in-house work will be adjusted by shifting people between departments. Also, there is already experience with decommissioning within the NII, and this knowledge will be used to train inspectors for their new tasks (Ascroft-Hutton and Storey, NII).

Haddon (NIA) likened the transfer between two types of reactors to an aircraft pilot learning to fly a new aircraft. While there is a high level of similarity between the skills required for both, additional skills are learned through simulators and other means to make employees familiar with the specific skills needed for a different reactor. When Sizewell B was built, there was no operating experience of PWR-type power stations in the UK. In this case, people were trained with simulators and through experience with American PWRs to bring them up-to-date.

Both Haddon (NIA) and Smith (DTI) also pointed to the importance of the new sector skills council (SSC) *cogent plus* which will become operational on 1 January 2004 and will act as a strategic body to identify skills shortages and make recommendation about future training programmes. As a background, *cogent* was formed as a SSC specifically for the oil, gas and chemicals industry. Recently, it has been enlarged to include the nuclear and polymer industry under the new name *cogent plus*. Smith (DTI) pointed to the synergies between these different industries. All five industries recruit essentially from the same skills pool of science and engineering graduates. All five industries are highly regulated and handle dangerous substances which require a strong safety culture. Furthermore, there are a number of job areas with similar skills requirements such as safety case writing. Thus, *cogent plus* should be able to act as an important body linking not only the different industries themselves, but also the industry and the education institutions to strategically lead on education and training programmes. Still, Smith (IMechE) pointed out that although there were some synergies to be gained from the SSC, “it is unlikely to alleviate the impending skills shortage in the reactor design area where experience rather than qualification is paramount.”

The SSC acts to bring together the various points mentioned above. There are few if any recognised professional certificates that are required to progress specifically in the nuclear industry (say, as compared to the generic and transferable chartered engineer status). This situation, together with the SQEP requirement by the regulators, can explain why companies in the nuclear industry prefer to do in-house training and rely less on university education alone. But a problem arises as this recruitment process provides little transparency in the industry as a whole as to which skills are in surplus and which are underrepresented. Here, in the light of the opinions expressed in the interviews, it could be argued that ‘cogent plus’ has a key role in standardising the in-house training programmes and SQEP requirements across the nuclear industry itself and possibly even with the other cogent plus industries. Laurence Williams, HM Chief inspector of Nuclear Installations, argued during a panel discussion at the “Visions 2003” nuclear conference on 18 June 2003, that “formalising SQEP training would ensure that consistent, high standards are maintained. The development and delivery of training may best be achieved by the industry and contractors working together” (Visions 2003). Smith (DTI) describes a “skills passport” scheme currently operated by *cogent* in the oil industry. This passport stores the skills and experience of its owner as certified by *cogent* and thus serves to standardise different skills and experiences in the industry and to simplify the matching of job requirements and skills supply. In conclusion, such a scheme, if implemented in the nuclear industry, has the potential to mitigate against skills shortages as it identifies the affected areas more quickly, and makes it easier to find people with the right skills to fill the respective positions.

One deficiency though, that is not addressed by *cogent* is the supply of highly specialised and skilled nuclear scientists. Here the degree of sideward mobility in the industry is much more limited. A key area of this issue is nuclear research, which will be discussed in section 4.4. below.

Transferability of skills between the areas of nuclear reactor operation and nuclear decommissioning seems to be an area that has not yet been fully explored. However, it can be noted that this area could, at least theoretically, offer an additional route through which the nuclear industry can retain skills in the sector. The skills supply in the decommissioning sector will be discussed specifically again in section 4.5.

4.4. Nuclear education and research in the UK

As mentioned in the last section, specific nuclear undergraduate and postgraduate education is not a necessary condition to enter the nuclear industry. Rather, the industry focuses on a variety of short courses and certificate courses that are offered as part of continuous professional development (CPD) programmes. For this reason, a full review of nuclear education at British universities is not pursued at this point. There is a comprehensive review by the HSE (HSE 2002) which gives an overview of nuclear undergraduate and postgraduate courses. Instead, the focus of this section will be different. As already indicated in section 4.3., the nuclear skills shortage *per se* was not seen as immediately threatening for the nuclear option in the UK. The fact that many tasks in the industry do not require specialist nuclear knowledge rather implies that the real challenge is to attract general science and engineering graduates into the nuclear industry. Furthermore, where university-trained nuclear knowledge is needed, it is often highly specialised and advanced. For this area, adequate research to maintain a high-level knowledge base would be essential. Furthermore, research could be seen as an essential means to keep the nuclear option open in the UK. New reactor designs, now explored through international research collaborations, could provide essential technological innovations that might, for example, overcome some of the economic difficulties discussed in section 3.2. In the light of this argument, this section will firstly explore the specific point of attracting graduates into the nuclear industry. Secondly, the state of nuclear research in the UK is investigated. As there are linkages between both issues, both topics will be discussed under the same heading.

A general problem, which was especially cited by representatives of the nuclear industry, was the bad image that the industry had in general. Haddon (NIA) states that the industry was seen as being in terminal decline. The current absence of any realistic prospect for new nuclear build combined with the emerging nuclear decommissioning and clean-up market created an image of "demolishing an industry" rather than "building something exciting, new" (Haddon, NIA). Mayson (BNFL) argued that as long as there was no sign by the government to support new nuclear build, it would be hard to recruit a continuous supply of skilled graduates. The Energy Board of the ICE sees "a new build programme" as "a key factor in encouraging recruitment and in retaining existing staff".

Spivey (DTI), however, pointed out that the NDA had already been renamed, after its previous title "Liabilities Management Agency" had been seen as too negative. Smith (DTI) added that the industry should take a more positive stance and sell the work that is carried out as "environmental remediation". Furthermore, it should be recognized that decommissioning and clean-up is actually a guaranteed statutory market, set up by the government, and worth at least £48bn, which in itself should be an attraction for graduates.

Salary packages in the industry were seen as competitive with other industries requiring similar science and engineering skills. This was confirmed by a YGN survey where members stated that the starting salary was one reason that attracted them into the industry. However, the nuclear industry does not just compete with other science and engineering industries. As Mayson (BNFL) lamented, their main competitor in relation to salary and job prospects is the financial industry in the City of London. Highly numerate graduates, even from science and engineering degrees, are in demand in industries such as insurance and investment banking and salaries are generally higher than in the nuclear industry.

Howarth (BNFL) pointed out that BNFL has a strong relationship with a portfolio of universities. This ranges from BNFL experts lecturing on university courses to students undertaking projects sponsored by the industry and hopefully working in research facilities and gaining experience on plant related issues. Offering prospects in research and practical application at BNFL is seen as one key to motivate students into the nuclear industry. Most notably in this respect, BNFL has set up four "university research alliances" (URA) with universities in Manchester (University of Manchester and University of Manchester Institute of Science and Technology (UMIST)), Leeds and Sheffield in the specialist areas of radiochemistry, materials, particle science and technology, and waste immobilisation respectively. Howarth (BNFL) explains that "BNFL decided to take charge of its own destiny and establish strong links with a few leading universities. By creating a critical mass in a few clusters, a research base could be established for the long term to create centres of international expertise and underpin UK requirements". Already, they have led, in the case of radiochemistry at Manchester, to a surge in students taking nuclear courses and consequently entering nuclear research (HSE 2002).

A further significant development in this area is the exploration of a potential centre of nuclear science at the new University of Manchester, once the merger of the current University of Manchester and UMIST is complete. According to Howarth (BNFL), this could act as a hub to connect those universities in the UK that undertake nuclear research and teaching. “It is hoped that this will improve the links with academia, industry, government and of course students such that all stakeholders would benefit.” Also, it could be the first point of contact for the envisaged “World Nuclear University” which was officially launched on 4 September 2003, at the time of writing, and the planned European Masters in Nuclear Engineering which is currently envisaged within the EURATOM framework VI research programme.

<u>Textbox 3 – The World Nuclear University (WNU) and the European Masters in Nuclear Engineering (EMNE)</u>

The WNU has four founding sponsors: The IAEA, the NEA, the World Association of Nuclear Operators (WANO) and the World Nuclear Association (WNA). It will comprise of a network of some 30 countries and bring together universities and research centres with strong programmes in nuclear science and engineering. Its stated aim is “to foster cooperation among its participating institutions - seeking synergies and mutual benefit while setting and enforcing high academic standards.” (World Nuclear University 2003). It also aims to create its own core facility at a yet to be determined place as a centre for “world-class expertise”.

The EMNE is currently designed by the “European Nuclear Engineering Network” (ENEN) under the EURATOM framework VI research programme. It aims to standardise education in nuclear engineering across Europe and pool resources from several European universities (ENEN 2003). Details are still to be published.

As outlined initially, research is also considered an important aspect in keeping the nuclear option open from a technological point of view. In particular, the Generation IV international research project outlined in section 4.2. promises radically new nuclear technologies that could address economic, waste and security concerns that have been and will be discussed in this report. However, the decline in public funding available for nuclear research led a number of interviewees to raise concerns about the future of this sector. Ascroft-Hutton and Storey (NII) point to the declining amount of money available to undertake nuclear safety research. Mayson (BNFL) argues that the government should become more active in research funding again for a variety of reasons. Firstly, the UK has to maintain its competence to select, license and operate new reactor designs, secondly, it has to engage actively in international research to keep abreast of new developments of new reactor designs and thirdly, in the light of an ageing body of academics and industry specialists, to provide underpinning for existing research programmes. Howarth (BNFL) furthermore points out that BNFL is currently shouldering the bulk of UK research expenditure, not only to support plant operations but also to maintain and operate research facilities and engage in international research programmes on both advanced reactor and fuel cycle design but also waste management. Smith (IMechE) argues that "by far the best way to maintain the required nuclear design skills is for engineers to work on new nuclear reactor designs".

In summary, there seems to be a convergence of the two issues discussed in this section. Various interviewees highlighted the difficulty of attracting science and engineering graduates specifically into the nuclear industry. One way to do this, which again was mentioned by various parties, was to offer interesting research topics and the outlook to explore "new, exciting" issues. At the same time, there is an international research programme and emerging international cooperation projects in nuclear research and education that do just that. If brought together, these factors could play an important part in keeping the nuclear option open in the UK.

4.5. The skill base and the NDA

As described in section 4.3, there are a number of skills that have overlap between nuclear reactor operations and the nuclear clean-up and decommissioning sectors. With this fact in mind, it could be asked whether people with the skills that are learned and applied in this emerging market could be trained more easily and quickly to work in reactor operations, should this be required in the future. If this were the case, the skills developed in nuclear clean-up could act as a hedge for future nuclear power developments of the UK.

In this argument, the NDA would have an important function to play. It is currently envisaged that the majority of civil nuclear liabilities in the UK are transferred to the NDA. The NDA would then negotiate contracts with interested parties to manage these liabilities with the objective of decommissioning facilities and cleaning up nuclear sites. It is currently estimated that the total value of these liabilities is at least £48bn, but it could be much higher once the true extent of the liabilities becomes known (Spivey, DTI).

The sheer size of this potential market has already attracted a great deal of commercial interest and none of the interviewees raised concerns as to the availability of the right skills in this area. On the contrary, Ascroft-Hutton and Storey (NII) expected it to be "an easy issue". Haddon (NIA) described how engineering companies like Bechtel or WS Atkins, which are expected to bid for subcontracts under the NDA arrangements, have small nuclear branches as compared to the overall size of the company. This fact should enable them to provide for and transfer skills internally from across a broad range of engineering disciplines as required. Hence, the commercial activity that the contracts are likely to generate is already expected to provide the basis for the right training and skills development in the area. A recent piece of evidence for this has been the recently established University of Birmingham PGCert course in Radioactive Waste Management and Decommissioning.

A second argument is the proposed remit of the NDA under the draft legislation to undertake research to underpin its activity where it deems necessary (see also section 4.2.3.). Spivey (DTI) sees the research role of the NDA as a "funder of last resort". There are two levels where the NDA has a research interest. Firstly, site specific research to support operations on site and to address specific problems there. Secondly, generic research to look ahead strategically. In principle, this can be very broad and can link in with existing research programmes such as the EURATOM Framework VI research programme and other international collaborations. In this second area, it will aim to strategically coordinate research with other bodies such as the research councils, *cogent plus* and the regulators. This is in line with the NDA's function as an organisation that has to "think beyond the short-term" (Spivey) and has to join up thinking within government strategically and long-term. Already, the relevant regulatory bodies have agreed with the NDA to work in partnership in this area through a joint research co-ordination body, as outlined in the Memorandum of Understanding between the NDA and the regulators (DTI 2003b).

In summary, the NDA will have an important role in developing skills in the nuclear sector. Its leverage will be greatest in two ways: Firstly, in designing the contracts it negotiates with firms that will manage the nuclear legacy. Here, the length of the contracts and the specific requirements for licensees to undertake research and training are of importance. Secondly, its role as strategic funder of nuclear research and development, in conjunction with other institutions, such as the research councils, regulators and the SSC, offers a further opportunity to maintain skill levels in the UK.

4.6. The nuclear skill base and the NII

As already mentioned in Section 4.3., the nuclear industry faces a retirement wave in the next couple of years. The NII is especially hit by this factor, as its age profile is even more skewed towards the older age groups than the nuclear industry in general. A significant majority of its inspectors are in the age band of 45-55. (DTI 2002) Thus, the "NII is faced with a perpetual challenge of how to attract a small cadre of experienced people from within the sector." (DTI 2002:9)

Ascroft-Hutton and Storey expect a "retirement wave" in the next "3,4,5 years". This means that a lot of experienced inspectors will move into retirement whose posts will have to be replaced. With the retirement, a lot of knowledge will be lost, and should there be a decision in favour of new nuclear build it would require some lead-in time to train the next generation of assessors to carry out the required tasks. There is anecdotal evidence that retired inspectors have come back on short-term contracts in the past to carry out specific tasks, but this can certainly not form a long-term basis for an institution with a mission statement of "regulatory excellence through continuous improvement".

A key aspect of fulfilling this mission is the close interlinkage of individual and institutional learning processes. The NII offers workshops and certificate courses to develop the skills of its staff. Furthermore, international exchanges either with other countries' regulatory bodies or through international institutions such as the IAEA or the NEA ensure that the NII is informed of and knowledgeable in the latest developments in nuclear technology. However, this applies mostly to the generic safety aspect of its job and not to new reactor design. Since new nuclear build is currently not on the agenda, only limited staff time can be devoted to updates on new reactor design.

In Mayson's (BNFL) view this could impose a serious constraint on the nuclear option, as it seems that they are already short of staff. Mayson (BNFL) cites the recent application to the NII by BNFL's previous CEO Norman Askew to review the new AP1000 reactor design. This application is stalled in the NII as they were unable to secure the resources in order to finance additional staff to carry out the task, while internal reorganisation would have seriously jeopardized their existing work.

The only way additional staff could be secured for the NII is through the strategic action plans (SAP) which the NII has to submit in order to get funding for its activities. In the current SAP, covering the years 2003-2006, there is no provision for staff that could carry out a pre-licensing review should this be required (Ascroft-Hutton and Storey, NII). In this respect HSE/NSD (2003:9) notes that "at present NSD [the 'nuclear safety division' within HSE] does not have the resource to do anything other than to continue its low key watching brief on new developments. If more than this is required we would need to recruit additional staff."

In relation to the expected retirements, Ascroft-Hutton and Storey (NII) note that once they have taken place it could take a lead time of several years to put together an experienced enough team again to carry out a pre-licensing review. Ascroft-Hutton (NII) gave an example from the late 70s when a team was formed to do a generic review on the principles of building a LWR in the UK. It took a team of 24 people with experience in AGR and fast breeder technology three years to produce this review from scratch. Most of these people then formed the core of the team that undertook the Sizewell B assessment. Many of those who worked on the Sizewell B assessment are now among the retirees.

In comparison, the most that the NII has done up to now in relation to new reactor design is a two-day workshop for 15 inspectors, organised by Ascroft-Hutton (NII), to inform on the AP1000. This event thus amounted to one staff-month of time used, which is a lot in relation to the time pressure under which the NII operates, but little in relation to the work that would have to be done should a pre-licensing review come on the agenda.

Smith (IMechE) also pointed to the costs involved in regenerating a team of NII inspectors. "If the design safety and licensing skills were allowed to dissipate, it would be possible to regenerate the capability, but this could add considerably to the cost of the new plant as the nuclear safety inspectors would probably require greater safeguards to compensate for their lack of confidence in the design capability." The argument made in section 4.4., that it is necessary to ensure British engineers have the opportunity to work on international projects in the absence of UK nuclear build, applies here as well. Strategic involvement in projects relevant to the nuclear option could ensure the maintenance of a core skill base that would be ready should decisions for new nuclear build be made.

In summary, the NII faces two distinct pressures on its work. Firstly, the NII's age profile represents a constant challenge to recruit suitably skilled and experienced staff. Secondly, resource pressures necessitate focusing the workload on key tasks, which currently prohibits the preparation of the NII for possible future work on new reactor design. Storey and Ascroft-Hutton (NII) agree that there is currently a shortage of resources at the NII. This, however, is less a consequence of a skills shortage than of a funding shortage. In the absence of top-level political commitment, Storey and Ascroft-Hutton (NII) both felt it would be difficult to apply for additional funding through the traditional channels.

4.7. Experience from Germany

This section will briefly outline some of the measures taken in the skills sector in Germany in response to the political decision to phase out nuclear power. As discussed in section 4.4. above, one reason cited especially by representatives of the nuclear industry was that the absence of new nuclear build was a major obstacle to ensure a continuous recruitment into the nuclear field. If this argument would hold true, it would apply even more to Germany, where the nuclear option is effectively shut politically.

There are a number of features that are similar to the situation in the UK. In Germany, there is a declining number of graduates in science and engineering degrees and the number of students that specialise in an area with a significant nuclear component is similarly falling (Fritz 2003). The age profile of the nuclear sector is similarly skewed towards the older age groups with the problem most pronounced for the nuclear installation inspectors; by 2010 300 retirees with significant specialist knowledge will have to be replaced (Sailer 2002). Representatives of the nuclear industry voice concern about the image of the industry and its ability to recruit adequately skilled staff in the future (Güldner 2003). It will now be briefly sketched out what actions were taken to address these issues.

In Germany, nuclear research is now clustered around the four so-called "competence centres for nuclear technology" (Kompetenzzentren Kerntechnik). Each centre is a unique combination of a research centre and local universities[14]. The focus of these competence centres is on those issues that will remain relevant to German nuclear technology, even without new build, i.e. research into safe nuclear operation and nuclear waste management and decommissioning. It is recognized that a new generation of employees with nuclear skills will be needed over the coming decades to carry out these tasks (Fritz and Kuzcera 2003).

A main feature of these competence centres is their access to significant amounts of public funding. Universities still fund the majority of their budget through public sources and the four research centres are typically sponsored through a combination of federal and state funding, supplemented by smaller amounts of funding acquired through projects with private partners. Thus, a first key feature of the German response to the nuclear phase-out decision is to focus the development of skills on those areas that will have a future in the industry and which guarantee the safe ongoing operation of the existing power plants. This is achieved through strategic funding by the state and the concentration of resources in those research institutions that already have significant expertise in the required areas of nuclear research.

Professor Knorr (University of Dresden) argues that the current level of funding is still not adequate and suspects a political motive of "drying out" the German nuclear skill base so as to make the phase-out decision irreversible. Yet, Fritz and Kuczera (1999) argue that the now agreed upon programme should "safeguard" an ongoing comprehensive nuclear education in Germany and maintain its status as "international partner" in international exchanges. Both emphasise, however, that this focusing of resources in the area of publicly funded research will leave it to the nuclear industry to maintain its ability to design and construct new nuclear power stations.

The regulation of nuclear power stations falls into the domain of the Technical Inspection Agency (TÜV). This is organised regionally, so that there are currently four main TÜV

[14] The four competence centres are: Forschungszentrum Jülich (FZJ) and University Aachen, Forschungszentrum Karlsruhe (FZK) and University of Karlsruhe, Forschungszentrum Rossendorf (FZR) and Technical University of Dresden, as well, as Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) and Technical University Munich

centres in Germany concerned with nuclear power regulation. Helmers, Wieland and Rettig (2003) outline how the "TÜV Nord Gruppe", the northern outlet of the TÜV, plans its succession management to replace the estimated 150 retirements over "the next couple of years". It is noted that training will face increasing financial pressures as firstly, current employees have to be taken out of their existing jobs in order to transfer their knowledge and, secondly, because the future demands for the TÜV's services are subject to change. The objectives of the succession management are the maintenance of the existing knowledge base and the transfer of it to new employees. However, it is anticipated that with the closure of existing power plants, the workload will shift and thus the employees, too, will become more concerned with tasks related to nuclear decommissioning. Overall, concern is raised in relation to the short-term pressure of an expected retirement wave while the long-term perspective is one of "cautious optimism".

From the point of view of the nuclear reactor industry the outlook is more bleak. Güldner (2003) points to an international nuclear revival and argues to "keep the nuclear option open" in Germany with particular reference to the expected difficulties in the recruitment market for nuclear engineers and scientists. In response to these anticipated skills shortages, Hohlefelder (2003) outlines measures taken by his company, E.ON nuclear, in order to attract a continuous supply of engineers and scientists to the company. Research collaborations, internships and financial incentives for new recruits are all part of the general package now on offer for current students.

In summary, recent developments in relation to the German nuclear skill base have taken into account the changing political landscape following the nuclear phase-out decision. Research institutions focus their limited resources on two key areas, nuclear safety and radioactive waste management. Regulatory institutions have to adapt to a changing future workload while guaranteeing the safe operation of the current fleet of nuclear reactors. The reactor industry will find it increasingly difficult to recruit its staff in Germany.

Many of these points are discussed controversially in the literature and the content of this part only intends to give a brief overview of the issues in Germany. A general trend seems to be that in the face of a firm political commitment to a nuclear phase-out, stakeholders in the German nuclear power community have reacted strategically to this decision. Resources are focused more closely on those parts in the industry that are seen as having a future. Research collaborations between institutions and coordination of research activity are seen as essential to safeguard the nuclear skill base in Germany.

4.8. Discussion of results

The main aim of this chapter was to identify where the nuclear skills shortage impinges most on keeping the nuclear option open in the UK and consequently to identify policy responses and recommendations. In the course of the interviews undertaken, several subheadings to this question were analysed. Section 4.3. tried to examine in more detail what skills were exactly needed to keep the nuclear option open. Section 4.4. analysed how graduates could be attracted into the industry and what role nuclear research could not only play in this respect, but also in the more general, technological dimension of keeping the nuclear option open. Section 4.5. and 4.6. examined the role of the NDA and the NII respectively while section 4.7. looked across the Channel to see what lessons could be learned from Germany, a country that recently announced its desire to phase-out the use of nuclear power.

A first key finding in this section is that a lot of work that would be involved in a new nuclear reactor project is "conventional" engineering which requires few specific nuclear skills. As evidenced in the emerging nuclear clean-up and decommissioning market, large engineering firms are pooling their general engineering resources with specific nuclear ones to create teams that can work in this area[15]. Transferability of skills between sectors within the nuclear industry and, to a lesser extent, between industries seems to be an option offering some potential, although it has not yet been fully explored by actors in the industry. In relation to the question of retaining a specific nuclear skill base for the nuclear option in the UK, these facts imply that resources can be focused on those aspects that are uniquely nuclear. Here, research and on-the-job training in actual nuclear projects seems to be the best way to retain a skill base. In the absence of nuclear build in the UK, opportunities have to be sought internationally, a task which will mostly fall within the domain of the nuclear industry.

Research, and especially collaboration in international research projects, is a second area that is vital for the nuclear option and integrates many points discussed in this chapter. Firstly, it could be one important way to attract graduates into the industry. Secondly, it could act to

[15] Unfortunately, these companies could not be contacted directly within the time and resource constraints of this study to explore further the specifics of this aspect.

support the current skill base and ensure a constant supply of nuclear specialist where necessary. Thirdly, it is seen as an important opportunity to stay abreast of new reactor design developments which could contribute to keeping the nuclear option open, a factor that is specifically relevant to the role of the NII. Ensuring adequate research into waste management and nuclear decommissioning will be a domain of the NDA, although this leaves scope for projects with spill-over effects into other areas of nuclear research. In Germany, although the nuclear option is currently closed politically, a continuous skill-base to ensure the safe ongoing operation and subsequent decommissioning of existing plants is seen as paramount. Nuclear research there will be increasingly done through collaboration of institutions and specialization in research on topics seen as having a long-term future. In this way, the skill base in Germany is retained even in the absence of new nuclear build, albeit reactor design capabilities are lost.

So who would fund these research activities in the UK? The government has stated that it wishes to keep the nuclear option open, hence it could be expected that those activities that are seen as essential in order to do so will receive state backing. However, there is already substantial private investment into various nuclear research programmes and it could be argued that since the benefits from this research will ultimately accrue to private companies, they should be the ones that put their money where their mouth is.

MacKerron (NERA) argues that from an economic point of view, “there is a case for public support for long-term research and development (R&D) into new reactor technology.” The argument here again is that new reactor technologies could overcome some of the obstacles, for example as outlined in sections 3.2. and 3.3. on economics and waste, currently preventing it from being a short-term investment option like other energy technologies such as gas or coal. In this case, there are public benefits from investing into R&D now and thus a case for government support. Moreover, since private companies cannot capture the total benefit of their R&D investment, this market failure could prevent the full amount of private investment flowing into R&D which would otherwise be justified by the expected public benefits.

More extensively, a ‘Fission R&D task force’ of ‘eminent’ UK scientist and engineers, commissioned by BNFL to undertake an ‘independent’ review of the current UK research situation, proposed a government nuclear research programme of £30m annually (Ruffles et al. 2003). In their report, the authors proposed a focus on four key areas to maintain nuclear power as an option: ”Providing support for the existing nuclear power generation programme, maintaining competence to select, license and operate new reactor systems, keeping abreast of international developments in the next generation of nuclear reactor systems and maintaining and developing competence in nuclear waste management.”

The IMechE, in a forthcoming position paper on UK energy policy, has similar recommendations with regards to the nuclear skill base. They suggest to focus on maintaining skills with respect to current and future designs and to assist UK companies to apply their skills in countries with nuclear construction projects, such as China and Eastern Europe (Smith, IMechE).

In the light of the above discussion, it seems that there is fundamentally a case for public support of nuclear research and development, so as to back-up government policy of keeping the nuclear option open. However, it is less clear, what type and level of government involvement is needed and where this should be focussed. From all the different aspects of nuclear research, future reactor development seems to be the most important and fundamentally most relevant to the nuclear option in the UK. There are two main aspects to it:

Firstly, the current policy-making process on radioactive waste management plus other regulatory requirements make new nuclear build before 2020 highly unlikely. By then the economics of current plant designs is likely to be overtaken by developments in other energy technology sectors, most notably gas and renewables. Thus, it seems important that the UK has the opportunity of selecting between different reactor types and has access to new and potentially more economic designs.

Secondly, the role of the NII is central to the nuclear option. Firstly, it is standard procedure in the licensing process that prior to any new plant building application, inspectors familiarise themselves with new reactor designs in a pre-licensing review. Furthermore, the NII is legally required to assess concrete building projects and grant operating licenses, and to inspect and evaluate ongoing operations of nuclear power plants. At the moment, the workload of the NII is mostly confined to the last area of inspection. In order to keep the nuclear option open, the first two parts are vital, thus action is required in this area if unnecessary and costly delays are to be avoided. Funding applications for the NII currently have to pass through a complicated hierarchy (Ascroft-Hutton and Storey, NII). They involve making a bid from the NII to the HSE, with the aim of the HSE supporting this bid and presenting it to the Department of Work and Pensions (DWP), the current sponsoring department. Subsequently, this has to be approved by the DWP and then finally presented to and accepted by the Treasury. The current Minster of State for Work with responsibility for the HSE budget is Des Browne. His portfolio ranges from items like the "New Deal" to "E-Government" (DWP 2003) and it is unclear whether he would prioritise the NII's demands in the absence of top-level political commitment when trade-offs in his budget have to be made[16].

In the light of these two aspects, a government programme ensuring British involvement especially in the Generation IV international research collaboration seems to be an important part of keeping the nuclear option open. Specifically, to familiarise itself with new reactor technology, the NII normally conducts pre-licensing reviews of new designs prior to the formal licensing process. By getting involved in international research programmes, it could maintain and develop an important knowledgebase. It has been stated by representatives of the industry, the government and not least from the NII itself that should the current knowledge base be lost due to resource constraints it could take "years" and involve significant costs to regenerate this skill base. This does not mean that the nuclear option would be 'shut' in the UK, but that substantial delays would be incurred in order to open it up again.

Generally, nuclear research is currently in a fragile state in the UK. One response to the resource constraints in this area has been the linkage between industry and universities at various levels. This allows for a better coordination of research and education and makes the best use of the limited resources available. This approach is reflected in Germany with the introduction of "competence centres", research clusters that specialise in certain areas of nuclear research, thus avoiding competition for the same funding sources and strengthening key competencies. From a perspective of 'keeping the nuclear option open', it does not seem necessary in the light of the above discussion to provide additional funding in areas where public-private arrangements are already in place.[17]

[16] Time constraints prevented taking up this issue with people within the HSE or the DWP.
[17] An argument that would call for independently funded research beyond the existing public-private partnerships was pointed out by Nuttall (Cambridge University). This is essentially concerned with the fact that a high level of corporate involvement in nuclear research could lead to declining public trust and confidence in its results.

The nuclear skill base in the UK is still strong, "leading worldwide in many areas" according to Haddon (NIA). Hence, the real issue to which the discussion in this chapter comes down to is the mechanism by, and degree to which the government should invest into the nuclear skill base through supporting research and development activities. In section 4.2., the skill base was described as an overhead to the industry. In the absence of activity that could generate the revenue necessary to invest into the nuclear skill base, the private sector will refrain from doing so. Other sources for funding this investment have to be identified. To some degree, resources could be invested more efficiently through strategic collaborations by the affected stakeholders, as witnessed in Germany and increasingly at UK universities as in the case of the URA. However, fundamentally the private sector will only fund so much of the nuclear skill base as it sees necessary to undertake those business activities that have a future market. If the government has stated that it wishes to keep the nuclear option open, it implicitly made a public policy choice to sustain those areas of the nuclear skill base that have no immediate future but would be needed should the option be chosen at some point in the future. An overview of the policy issues arising out of this chapter is given in textbox 4 below. Their implications will be discussed again in section 6.2.

Textbox 4 – policy options for government support of R&D

- Extent of government support (near market/ blue skies)
- Scope of government support (reactor design/safety/waste)
- Type of government support (direct/indirect)
- Nature of government support (grant/tax credit/in-kind)
- Duration of government support (start-up/on-going/long-term)

Also, when the government would have to make decisions about new nuclear build, it would have few independent scientists without a financial interest in such a programme remaining to assess the available options.

Chapter 5 Safety and Security in the light of recent terrorist attacks

The last chapter outlined policy recommendations that were seen as vital to maintain the UK nuclear skill base as part of the nuclear option. This chapter will now analyse if measures are similarly needed to respond to safety and security concerns in the wake of September 11th, 2001.

Statistically[18], nuclear reactors are among the safest ways of producing electricity. Multiple safety systems operate to ensure that the risk of a radiological release into the environment is minimized in accordance with the 'as-low-as-reasonably-practicable' (ALARP) principle, which will be discussed below. However, in the wake of the terrorist attacks of 11th September 2001 (subsequently referred to as '9/11'), the threat of external attacks on nuclear facilities received increasing attention. Scenarios included the deliberate crashing of aircraft, infiltration of a plant by armed intruders or some form of weapons fired onto a nuclear facility.

The aim of this chapter is to assess the impact of the events of 9/11 on the nuclear option in the UK. To limit the scope of this section it is assumed, due to the reasons outlined in section 3.3., that reprocessing is not part of the future nuclear option in the UK. Thus, the main nuclear facilities which are relevant in this section are existing and new nuclear power plants and spent fuel stores which are assumed to be on site of nuclear plants and protected under a concrete containment. It is furthermore assumed that the waste management option eventually adopted will have taken into account the risk of terrorist attacks and has thus adequate safeguards in place.

In principle then, there are five questions to be answered in this respect. Firstly, what are the implications of terrorist attacks for new reactor designs and safety regulation. Secondly, are existing nuclear power stations safe and secure to withstand terrorist attacks, thirdly, if not, can they be upgraded to ensure an adequate level of safety and security and fourthly, what economic implications would such upgrading measures have. A fifth question addresses the issue of public acceptability of nuclear power plants in the wake of 9/11.

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[18] I.e. in terms of deaths per unit of electricity produced

As a background, this chapter will firstly give a brief overview of the established safety regimes at nuclear power stations based on public domain information. Secondly, it will review post –9/11 public domain literature, discussing its safety and security implications for existing and new reactor design and waste management facilities. Where applicable, it will present results of the interviews conducted. The chapter will close with a discussion of the findings from the angle of public perception of the issue and possible consequences on the feasibility for future build in the UK.

5.1. Concepts in Radiological Protection

Before discussing the impact of the events of 11 September 2001 on nuclear safety and security, a background of the principles used in designing safety and security at nuclear sites is presented. These are the principles laid out in ICRP (1990) and the ALARP and tolerability of risk concepts.

Protection against potential adverse effects of radiation are founded on a conceptual framework proposed by the International Commission on Radiological Protection (ICRP 1990). This involves the following three principles:
Justification, which requires that exposure to radiation has to be offset by a benefit to the exposed individuals or society. This can include economic, social or health benefits.
Optimisation entails reducing the radiation risks to individuals or society as long, and to levels as low, as reasonably achievable. In the UK this is applied in the frame of the ALARP principle discussed in the next paragraph.
Limitation establishes that there are upper boundaries of radiation doses and associated risks which should be controlled and not surpassed.

As outlined above, the as-low-as-reasonable-practicable (ALARP) principle has a central role in ensuring protection from radioactivity. Underlying this is the assumption that there is essentially a trade-off between the benefits of reducing risks and the costs of doing so. ALARP demands that unless the costs are ‘grossly disproportionate’, risks are continuously reduced where possible. The costs to benefits ratio which would be considered ‘grossly disproportionate’ increases as the level of risk increases. This means that (all other things equal), greater costs would be justified in reducing a risk of 1 in 20,000 than a risk of 1 in 50,000 (POST 1996).

In the UK, there are certain thresholds beyond which risks are seen as unacceptable. For this, the "Tolerability of Risk" (ToR) framework is used (see figure 1 below). In the case of nuclear power, the HSE assumes that risks are intolerable at a level greater than 1 in 10,000 per year for a member of the general public. At the other end, it was a standard assumption that risks were broadly acceptable if they were lower than 1 in 1,000,000 per year. This would mean that ALARP would no longer apply if risks were demonstrated to be below that level (POST 1997). However, recently the idea of a universally-accepted lower boundary of tolerable risks has been rejected and each case is now judged on its own merits to ensure that ALARP is applied even in the "broadly acceptable" region until the benefits of further risk reductions are outweighed by its costs (HSE 2001).

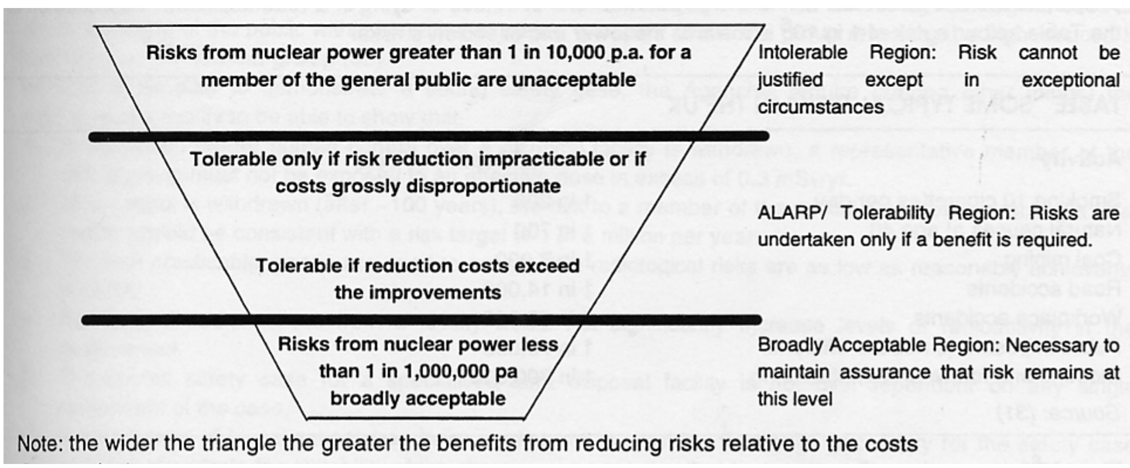

Figure 1: Tolerability of Risk principle. Originally, the lower region of risk (less than 1 in 1,000,000 events per annum) was originally though broadly acceptable. However, with the publication of HSE (2001) it is common practice in the UK to apply the ALARP principle even in this region.

5.2. Traditional Safety Measures at Nuclear Facilities

With the principles in the last section as a background in mind, it will now be outlined, how safety and security measures are implemented in UK nuclear facilities. Firstly, the safety assessment principles of the NII are presented and consequently, the concepts of ‘defence in depth’, design basis threat and probabilistic risk assessment are discussed.

The safety of nuclear facilities in the UK is guided by the Safety Assessment Principles of the HSE, which take into account the principles laid out by the ICRP and the concept of ToR. Operators of nuclear facilities have to present a safety case to the NII for assessment and will only be granted a license to operate if the NII is satisfied that the plant is “as safe as reasonably practicable” (HSE 1992).

For nuclear reactors, the overall philosophy of safety can be described under the heading ‘defence in depth’. Three concepts are commonly seen as central to this, often called ‘the three Cs’: controlling, cooling, and containing (Hewitt and Collier 2000). The reactor core power level is kept at desired levels by controlling the nuclear chain reaction and stopping it when necessary. Even when a reactor is shut down, there is still a considerable release of energy from the fuel due to the radioactive decay of the accumulated fission products. To keep the core cool, several independent cooling systems are in place to prevent a reactor meltdown. Finally, there are containments in place, which are physical barriers to prevent fission products escaping into the environment should the other defences be compromised.

Textbox 5: The Automatic Protective System (APS)

The APS monitors key parameters that are critical to the safe operation of the nuclear power plant. Whenever one of these parameters exceeds their design margin it can initiate an automatic shutdown. Typically, each parameter is measured by three separate instruments. If at least two of the three instruments show an exceedance of the relevant parameter, they automatically trigger a shutdown. This ‘majority voting’ system is to maintain a high reliability while minimising unnecessary shutdowns. APS are designed to be reliable typically better than 10^{-6} failures per annum. The majority voting system incorporates the ‘duplication’ logic whereby the breakdown of one instrument does not automatically lead to a break down of security.

Also, different ways of measuring the same parameter ensures ‘diversity’ which reduces the risk of common mode failure – whereby similar components might fail simultaneously due to, say, some foreseeable external factor (Bennet and Thompson 1989).

As described above, the overall idea is to have several barriers to radioactive release in place, each again with multiple defence layers, based on the concepts of ‘duplication’ and ‘diversity’, for which there is an example in Textbox 5 above. The fundamental principle here is that if one safety system fails there is a backup to take up its function, whose operation does not rely on the same systems (e.g. electricity supply) as the one before.

In order to determine the level of protection required at each of the layers just described, the method of probabilistic risk assessment (PRA) is used (OECD 2003). PRA involves creating an event tree of those events that could lead to releases of radioactivity from a nuclear power plant. The likelihood of each step in this event tree is measured or estimated and then multiplied along each pathway of the event tree. Thus, the probability for each event occurring is computed (see figure 2 for an example). Commonly, historic data of the reliability of individual components of the safety systems are used, but also modelling of events with computers or miniature structures is carried out (Rasmussen 1990).

To defend a nuclear facility against attacks from outside, the ‘Design Basis Threat’ (DBT) scenarios are created and subsequently, adequate defence mechanisms are devised. Examples of a threat could include intruders attempting to enter a plant while defence mechanisms include security guards, fences and other barriers. In the UK the office of civil nuclear security (OCNS) is responsible for identifying the DBT and ensuring that adequate measures are taken against them. However, DBT scenarios and their consequences are not in the public domain. “For security reasons, the DBT is classified SECRET and no further details can be published.” (OCNS 2003:4)

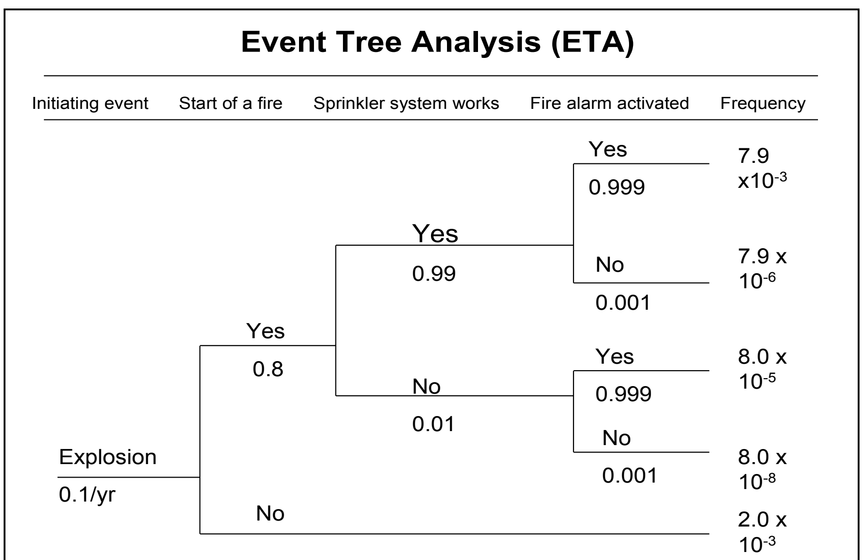

Figure 2: Example of an event tree (from Rasmussen 1990)

5.3. The Safety and Security Environment post 11th September 2001

In this sub-section it will be attempted to analyse the impacts that the events of 11 September 2001 had on the safety features presented above. In principle, there are at least three ways of increasing safety and security against terrorist attacks. Firstly, the physical robustness of plants can be upgraded, secondly, the level of security measures around a plant can be increased and thirdly, measures to identify and stop terrorists before they carry out attacks can be improved. Sources for this are firstly public-domain literature and secondly interviews with stakeholders in this issue. A specific focus were cost implications of possible upgrades of plant safety and security.

While undertaking research for this section, a first key limitation to collecting information on this issue became clear in the OCNS annual report 02/03 (OCNS 2003:13): "Section 79 of the Anti-Terrorism, Crime and Security Act 2001 introduced a new offence for anyone to make an intentional or reckless disclosure of information that might prejudice the security of nuclear premises or material." There is not a precedent case in the UK yet, as to what constitutes "an intentional or reckless disclosure of information", but it could be expected that the information that was available in the public domain was limited to the necessary minimum.

5.3.1. Physical robustness of current and planned nuclear facilities

In this area there are a number of conflicting studies. Firstly, there are two studies by the Swiss and German governments which see some problems with containment structures at older plant designs and demand further investigation. Secondly, there are studies and opinions released or commissioned by the nuclear industry, that underline the physical robustness of existing and future plant design. Lastly, there are studies by environmental NGOs which emphasise the large-scale catastrophe that could result from, say, an airplane crash on a nuclear facility. The problem of designing physical protection of nuclear power stations for terrorist attacks will be considered.

Two important studies were commissioned by the German and Swiss government respectively

(RSK 2001, HSK 2003). They both analysed the level of protection against aircraft crashes of existing nuclear power stations in the two respective countries. Although different in their details, there was one common theme that was similar in both studies. While it was ascertained that newer generations of nuclear power stations have a high level of protection against aircraft crashes, older nuclear power plants were generally thought not to be able to withstand a deliberate attack with a plane. This was primarily due to different strengths of the external concrete containment which in turn reflects the different requirements for new nuclear reactors in the past. Still, even for the latest designs installed the two studies could not rule out completely that an aircraft crash could result in radioactive release. A further investigation undertaken by the German regulatory body RSK was classified in 2003 and is not available in the public domain.

In relation to new designs, BNFL maintains that the AP1000 provides adequate levels of safety and security. Mayson (BNFL) emphasizes that the "…AP1000 containment and shield building provides protection from external hazards commensurate with current and anticipated requirements. Studies have been performed that demonstrate the capability of current nuclear plant design to withstand credible airplane crashes."

The Nuclear Energy Institute (NEI 2002), the nuclear industry association in the USA, commissioned a report by the Electric Power Research Institute (EPRI) on the physical robustness of both nuclear power plants and waste stores in the USA. Again, the detailed conclusions of the report remained confidential, but the general information released argued that the current nuclear plants and fuel stores were able to survive the crash of a Boeing 767-400 without releasing radioactivity into the environment.

Floyd (NEI) also reports that the industry has been asked informally by the US Nuclear Regulatory Commission (NRC) "about the feasibility of installing aircraft shields of various types to intercept aircraft". In this respect, he noted that "due to other regulatory requirements that any structures whose failure could jeopardize safe shutdown equipment must be seismically qualified […], the costs of these shields are prohibitively expensive and have not been pursued."

Lazo (NEA) stated that studies, following 9/11, confirmed the view that nuclear power plants would withstand terrorist attacks which meant that no major modifications were recommended. Overall, he ascertained that "the costs of any emergency response modification following the 11 September terrorist attacks have been easily internalised by the nuclear industry". However, he was not able to give quantitative estimates of the scale.

Against this, there are at least two reports that point to the potential dangers that could result from a successful terrorist attack on a nuclear facility. Schneider and Large (2002) pointed in a conference presentation especially to the vulnerability of the Sellafield waste management facility. As mentioned in section 3.3.1, approximately 87% of all radioactivity from radioactive wastes is stored there. Since facilities constructed before 1980 were mostly built without the possibility of a significant airplane crash included in the design, it was argued that many nuclear reactors and facilities in Sellafield could pose a severe risk to the environment. This is confirmed by an NII report (HSE/NII 1995) which outlines: "The crashing of a large commercial or military aircraft into the B215 building (making worst case assumptions such as aircraft size and direction/trajectory) could cause penetration of the concrete cell shielding, possibly followed by penetration of a [Highly Active Storage Tank] (HAST) by flying debris, resulting in the release of HLW into the cell and subsequently a release of radioactivity to the environment."

In a memorandum submitted by Thompson (2002) to the UK House of Commons Defence Select Committee, it is outlined that especially the liquid HLW, which are stored in steel tanks in partially above ground concrete cells in Sellafield, pose the greatest risks. Again, it is suggested that the facilities which were built in the 1950s could not contain the material in the event of a direct crash of a large aircraft. In this respect, the House of Lords Science and Technology Select Committee argued in a report (House of Lords 2001) that, in the light of the terrorist attacks of 9/11, "serious thoughts" should be given to moving the remaining liquid HLW into underground storage.

The points raised in these reports point to an issue that emerged post-9/11. Historically, the design of the physical protection of nuclear power plants only reflected the perceived safety need of its time. Thus, the PRA in the design of new nuclear power plants for a long time did not take into account the impact of large aircraft. Moreover, the usage of airplanes as a terrorist weapon was not included up to 9/11, although the potential impact of this mode of attack was already discussed as early as the 1970s (Krieger 1975).

Large (2003) questions the validity of using historic data in cases of terrorist acts. He argues that, in the past, it was assumed that it could only be by *accident* that an airline crashed into a nuclear power plant with a pilot attempting to avert or limit the impact of the accident. Assumptions about frequency of such an event and magnitude of impact were set accordingly. In contrast, in the post-September-11th environment it now has to be assumed that terrorists would fly *intentionally* into a nuclear power plant with the aim to maximise damage, thus creating a totally different risk profile.

OECD (2003:106) argues that risks from terrorists are hard to quantify in principle because of the many socio-economic influences that underlie it. Specifically, it argues that its risks "cannot be quantified using historical data, […] because of the deep changes they have undergone in the past years." Thus, it is furthermore argued that, while it is already problematic to use quantitative estimates of terrorists' intentions, the nature of terrorism itself has changed over time.

With respect to new designs, it cannot be examined how these considerations impacted on the calculations that underlie the design of the AP1000 as it was not possible to obtain information about this either from BNFL directly or from independent sources for this study. However, given that the design for the AP600, the basis of the AP1000, was completed in 1994 and that a design license was granted by the US NRC in 1999, it could be assumed that these post-9/11 considerations were not taken into account. A deliberate attack by an airplane on a nuclear power plant was not included in the DBT of the NRC pre-9/11 (Hirsch 2002). The AP1000 currently awaits design certification expected to be granted in 2004. Mayson (BNFL) states that "the AP1000 design satisfies US NRC requirements for DBT established after September 11, 2001." However, the complete DBT is not in the public domain, so it is not possible to examine to what extent the NRC has modified the DBT. POST (2003) comes to the conclusion that aircraft crashes are still not part of the DBT.

The aim in this section was to analyse the physical robustness of nuclear power plants in the light of 9/11. A number of studies with conflicting results have been presented and it has been outlined how confidentiality concerns have prevented the analysis of some of the information.

In relation to the nuclear option, a primary concern is with new reactor designs. Here, BNFL is confident that its AP1000 design is able to fulfil all regulatory requirements. Although questions have been raised in other studies about the extent to which containment shields are able to withstand, say, the impact of an aircraft crash, it has not been possible within the scope of this study to find a definite answer to this in relation to new design. Inferring from studies on existing designs would lead to the assumption that there is still a non-zero probability that a terrorist attack, such as an aircraft attack, could lead to the release of radioactivity even from new plant design.

In relation to costs there is the aspect of retrofitting existing power stations and design modifications of new reactors. Floyd (NEI) points to the costs of one defence mechanism for existing reactors, anti-aircraft shields around nuclear power station, as prohibitively expensive. However, in principle, Lazo (NEA) argues that numerous studies in different countries showed "that nuclear reactor containment buildings would withstand such attacks without catastrophic effects, thus no major modifications were, to the best of my knowledge, recommended." In relation to new design, BNFL is confident that its AP1000 design "has the robust barriers that will stand it in good stead for UK licensing". The statements above are inevitably skewed towards the nuclear industry and reflect a degree of engineering optimism. If the confidence on the side of nuclear developers holds true and the regulator in the UK agrees, then indeed the cost impacts of 9/11 for new designs and possible modifications of it would be virtually non-existent. However, even in that case the issue comes down to public trust in the industry and the regulator as the exact specifications in the reactor design and indeed the DBT are not publicly available to assess, for example, to what limit the ALARP principle was applied. This topic will be revisited in section 5.4.

5.3.2. Security measures at nuclear facilities

Apart from the physical robustness of plants, security can be implemented on the ground through security measures around nuclear sites. This sub-section analyses what measures have been taken and what the cost implications were in this area.

Again, confidentiality was a key limiting factor in this section. Laurence Williams, HM chief inspector of nuclear installations, states (Williams 2002:2): "It is not government policy to disclose details of security measures taken at civil nuclear installations and hence I cannot go into the detail of what we are doing. However, my colleagues in the Office of Civil Nuclear Security who regulate security at our civil licensed sites ensure that our licensees apply stringent security measures at their sites."

However, OCNS (2003:9) similarly states: "It would not be appropriate in a published document to comment in any detail on continuing work to strengthen security arrangements at civil nuclear sites in the aftermath of the terrorist attacks in the United States, Indonesia and elsewhere since September 2001."

The single official source that discusses security measures after 9/11 in some detail is OCNS (2003). The measures taken in the UK included chicanes, searching vehicles and personnel and additional protection of sensitive areas. (OCNS 2003)

In terms of the costs the OCNS has a budget of £1.8m, of which 25% is spent on site security, i.e. £450.000. Kirwan (2001), director of Strategy and Business developments at British Energy, states that security improvements at all its then nuclear power stations in the UK, USA and Canada were priced at £10m per annum. This is against an annual turnover in 2002 of £1.5bn.

For the USA, the NEI states that the nuclear industry had invested some $370m in security-related improvements on nuclear reactors since 11 September 2001. As there are 103 nuclear power reactors in the USA, this implies a spending of about $3.5m per nuclear reactor. Total operating costs in the nuclear industry in the USA were approximately $2.4bn in 2000 alone (OECD/IEA 2001).

It cannot be assessed whether the measures taken were 'adequate' in response to the threat except that companies complied with what the regulator considered necessary. As in the concluding section of 5.31., this again raises the issue of public trust. The exact undertakings on the side of the regulator and the regulated companies are not in the public domain due to security confidentiality, thus it cannot be assessed what level of security was considered adequate by the regulator and how it was satisfied.

Greenpeace had two successful incursions into the Sizewell B nuclear power plant on 14 October 2002 and 13 January 2003, and subsequently claimed that security levels at power plants were inadequate. However, OCNS (2003:16) maintains that these were isolated incidents and that protesters were never in a position to reach any sensitive areas.

The ‘Western Daily Press’ newspaper was able to charter a plane on 1 November 2001 and fly at 2,000 ft directly above the Hinkley Point nuclear power station in Sommerset. Up to that point, there was no restricted airspace in the UK. Consequently, a 5-km no-fly zone was established around UK nuclear facilities (Llwyd 2001).

In summary, there is little information in the public domain in order to assess the full implications of 9/11 on security measures at nuclear sites. OCNS maintains that security at nuclear sites has improved, and Adrian Ham (2001), the director general of the NIA, points out, that security of nuclear sites is constantly reviewed and “if either the companies believed that it would be safer not to run plants for any reason, whatever it is, or the NII take the same view, they would order them to be closed.” Again, central to this statement is the matter of public trust which will be taken up again in section 5.4.

Where costs have been cited, as in the case of BE and the US nuclear industry, they have been relatively small in relation to the size of the industry. Hence, although very limited data was presented in the above section, it can be concluded that the economic impact of upgrading security measures at nuclear sites to a level which is acceptable for regulators is likely to be small relative to the overall size of the industry.

5.3.3. General counter-terrorism measures

The German study on nuclear site security (RSK 2001), mentioned in section 5.3.1., recommended that the best way to counter the increased terrorism threat level is to reduce the probability of a plane-hijacking in the first place. This requires increased counter-terrorism measures by the state to identify terrorists before they can enter a plane.

Although there is no official statement on the UK strategy in this respect, newspaper articles (i.e. Independent on Sunday 2002; Sunday Times 2001) and a Greenpeace publication (2003), lead to the assumption that this aspect plays an important part in the overall UK nuclear security strategy. Greenpeace (2003:3) states in a critical assessment that "… the UK relies upon detecting the terrorist intent in good time to be able to avert the attack, rather than requiring the operator to physically modify and strengthen the plant." A more detailed discussion of UK air defence can be found in a House of Commons Defence Select Committee report from July 2002.

Cost implications from increased state activity in counter-terrorism measures are hard to pin down to individual sectors. Thus, it is hard to quantify specifically, how much the increased measures to protect nuclear power plants cost. The Home Office states that "while we cannot provide a breakdown of funding to individual agencies, for security reasons, the national Security and Intelligence Agencies overall received funding in excess of £990 million in 2002/2003 and will receive more than £1099 million in 2003/2004" (Home Office 2003).

In summary, it is not possible to discuss in detail the importance of general counter-terrorism measures for nuclear sites security. OCNS (2003:4) alludes to "intelligence about the motives, intentions and capabilities of potential adversaries" as a basis of the DBT. Hence, cost estimations cannot be done at this point. However, it is certain that those costs that have arisen so far have mostly been met out of public funds.

5.4. Implications for the nuclear option

The aim in this chapter was to evaluate the impact of the events of 9/11 on the nuclear option in the UK and especially the possible economic consequences that could arise out of design changes and upgrades. Clearly, the information presented is insufficient to evaluate with any degree of certainty the full implications of 9/11. The issue of confidentiality was a recurrent theme in this area and neither the industry nor the concerned regulators were in a position to provide detailed information. Lazo (NEA) sums up the view from this perspective as follows: "Following the 11 September attacks, every nuclear nation in the world performed extensive re-evaluation of the structural integrity of sensitive facilities, particularly looking at crashes of large aircrafts. These studies resulted, I believe, in the view that nuclear reactor containment buildings would withstand such attacks without catastrophic effects, thus no major modifications were, to the best of my knowledge, recommended."

Thus, in terms of direct costs it could be assumed that the economic impact of 9/11 was largely confined to additional site security measures and increased state activity in counter-terrorism. In the following, it will be briefly discussed, what indirect costs could stem from the events of 9/11.

In this respect, it has to be noted that the debate so far comes down to a matter of trust. Do people trust the industry and its regulators in their statements or are they more receptive to environmental NGOs that point to the potentially catastrophic impacts? This leads to the fifth question outlined initially, the issue of public acceptability of nuclear power plants in the wake of 9/11.

5.4.1. Risk Perception and Public Trust

One area of risk research is risk perception. Slovic et al. (1980) show in a psychometric study that factors such as familiarity with and individual control over a particular risk and its 'dread factor' are important influences on people's perception of risks. Nuclear power fits in this framework at one extreme. It is relatively new and unfamiliar, it seems to be 'imposed' on local communities in the sense that few people would choose explicitly to have a nuclear power station built nearby. Lastly, the dread factor, especially in the light of 9/11, is considerable. (Grimston and Beck 2002:31).

Consequently, it seems that the acceptance of nuclear power in society relies to a considerable extent on the public's trust in the institutions that are to guarantee the safety and security of these facilities. Given especially the dread factor involved, keeping open the nuclear option in the UK requires active communication of what is done. Furthermore, given the requirement of a public inquiry for any new nuclear power station planning application, the nuclear industry and the regulator would have to make the case for safety and security of nuclear power under close public scrutiny in any case. While the public inquiry itself is not the main issue, the information released is likely to become the subject of debate.

O'Riordan et al. (1996) asked people about their trust in different institutions and found that information communicated by environmental NGOs was trusted to be more truthful by a considerable margin than if it was communicated by government or industry. Although not referring to the nuclear industry in particular, this could present a significant challenge for it. Moreover, recent events in the nuclear industry, from falsified documents in a MOX-shipment from BNFL to the near-bankruptcy of British Energy, are not likely to have helped to build public confidence. Also, a recent survey on public opinions on the nuclear industry in the EU found that a majority of a representative sample of UK respondents tended to disagree or strongly disagreed with a statement which ascertained that the nuclear industry was open and transparent with respect to information about nuclear waste (European Commission 2002).

Hunt (2001) describes how in a front-end consultation study in relation to radioactive waste people were unwilling to hand over the power to make decisions to people or institutions they did not trust. In the above-mentioned consultation, the MoD attempted to determine what process was needed to arrive at a publicly acceptable way of decommissioning old nuclear submarines. Although this study was not concerned with nuclear power itself, the fact that security confidentiality played an important role and also the linkage of nuclear power and radioactive waste in the public's perception (see section 3.3.5.; Poortinga and Pidgeon 2003) made it appropriate to consider this study. In a further interview, Hunt explained that the issue of security of confidentiality itself was not the major one. The general feedback from the workshops undertaken was that people generally accepted the need for confidentiality out of security concerns when it was explained properly why confidentiality was needed in each case. There was, however, a reluctance to accept blanket statements with respect to assurances over safety and security. People wanted acknowledgements that mistakes do happen and that institutions are aware of it and demonstrate that they incorporate it into their behaviour.

Hunt argued that trust building was an essential task for the industry if it wanted to keep the nuclear option open. Here, from her perspective, the main problem was the reluctance of the nuclear industry to engage in an open dialogue. This could be summed up in the words "Institutions have to listen!". Dialogue should not be seen as a PR exercise and also not as a matter of persuading other people to take the industry's view point on the issue. Rather, to have an effect in terms of trust building, it has to be an open and two-way process. Hunt suspects that the industry is actually scared of this form of engagement and does not want to lose its frame of the debate[19]. The industry would have to accept that people would frame the debate differently than the industry would like and would have to engage with these viewpoints. For example, while industry sees the debate around the nuclear option as one on providing carbon-free electricity safely and with minimal waste arisings, other people might raise issues about large-scale infrastructure projects being imposed on them or producing a potential source for nuclear weapons. In this sense, the debate turns into a matter of control over the debate.

With respect to a planning enquiry in the case of new build, Jane Hunt is 'convinced' that energy policy in general will come up as an issue, when the topics for the enquiry are scoped, as people will want to discuss not just the narrow local question of a new plant but the wider necessity for new build in general. Specifically, the issue of radioactive waste is likely to be raised, as well, again referring to the linkage in public opinion of this topic and nuclear power (Poortinga and Pidgeon 2003).

5.5. Discussion of results

This chapter had the aim to evaluate both the direct and indirect impacts of the events of 9/11 for the nuclear option in the UK. Due to confidentiality issues in this area and the dominance of grey literature such as government, official agency's and industry publications, very limited information was collected and thus all conclusions can only be indicative in nature.

The probability of radioactive release even with new designs is non-zero. Direct costs that could influence the economic viability of future nuclear build and thus the nuclear option in the UK appear to be limited. Representatives of the nuclear industry are confident that new designs are resistant to terrorist threats and thus could operate without significant alterations to existing design plans. This assessment cannot be validated openly and a number of concerns remain. Older nuclear facilities were not designed to withstand terrorist attacks on a scale as seen today. Due to the security confidentiality, it cannot be assessed how the ALARP

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[19] 'Framing' or problem definition can be defined as "the lens through which an issue is seen – different lenses provide different ways of seeing... paying attention to the way a problem is framed is paying attention to the question of 'what is this issue about?'" (Hunt, Day and Kemp 2001)

principle was interpreted after the events of 9/11. Issues with the assessment methods for designing physically integral structures have been outlined.

Indirect costs could potentially become more significant. Here, again the issue of confidentiality due to security reasons plays an important part. Any new nuclear power plant in the UK would have to go through a public inquiry which would probe the public's confidence in statements that cannot be outlined in public due to security considerations. Furthermore, the necessity for nuclear power as compared to other technologies might have to be justified. This has to be seen against a backdrop of public distrust of the industry, perceived lack of transparency and perceived inability to deal with radioactive waste. Costs could then stem directly from undertaking the public enquiry, possible ensuing measures that are implemented to enhance public confidence in the industry's design and general opposition against new nuclear build that could become manifest in direct action of various sorts. Thus, these costs affect in general the image of the involved companies, a factor that increasing attention is paid to in the framework of corporate social responsibility (CSR)[20].

In conclusion, there is potentially an issue in the public acceptability of nuclear power. This arises out of a situation of heightened perceived risk of nuclear power plants in the public while at the same time, an open and transparent discussion of nuclear power is curtailed by the need for confidentiality in the security environment post September 11th, 2001.

[20] In the financial year 2002-2003, BNFL produced its first ever CSR report, "Our CSR journey", to address the various concerns raised for example by environmental NGOs. It is available from their website (BNFL 2003).

Chapter 6 Evaluation of Results and Conclusion

Chapters 3, 4 and 5 illuminated four different issues that could influence the UK ability of keeping the nuclear option open. This chapter will now evaluate the different results arrived at in the last chapters, give an outlook for further research and make some concluding remarks on the basis of this analysis.

6.1. Evaluation of Results and Areas for Further Research

This study's aim was to analyse the implications of the policy decision to keep the nuclear option open. Its objective was to evaluate nuclear power on its own merits in four areas central to this question, the economics of nuclear power, radioactive waste management, the UK nuclear skill base and safety and security implications of recent terrorist attacks. Certain issues could not be included within the scope of this study. These were among others:

- Questions of proliferation of nuclear material
- A critical discussion of historic subsidies to nuclear research and reactor construction
- An overview of issues regarding spent nuclear fuel reprocessing

Also, more generally, this study did not evaluate the nuclear option in relation to other electricity generating technologies such as gas, coal or renewables. As mentioned in the introduction in chapter 1, it was not the aim of this study to make a judgement on whether the nuclear option should be kept open. In order to do this, UK energy policy more generally would have had to be included in the study scope. This in turn, would have required analysis of each energy technology in order to be able to weigh the various costs and benefits against one's policy aims. In this context, this study can be seen as an input to such underlying analysis.

Some of the findings presented could also be relevant to other countries. The analysis of nuclear economics in a liberalized electricity market is likely to be applicable to other countries with such market environments. This is especially relevant to the EU, which aims, through the EU directive 2003/54/EC, to open up the European electricity market to competition and private ownership. Also, there are currently a number of countries worldwide, such as the USA, France and Germany, that are in the process of exploring options for radioactive waste management. Thus, the issues raised in section 3.3. on radioactive waste could equally be applicable.

Conversely, the issues raised in section 4 are likely to be more UK specific. Each country's nuclear industry and underlying educational institutions are differently structured. Some countries have new nuclear build programmes in place, while others are actually phasing out the use of nuclear power. Thus, government policy with respect to the nuclear option is highly dependent on each country's specific energy policy and the government's objectives and priorities on this.

The safety and security implications of recent terrorist attacks, on the other hand, are again a more global issue. A number of countries in Europe and America embarked on significant nuclear power programmes in the 1970s when the deliberate attack of an aircraft on a nuclear power plant was not included in the basic design. Although this study did not come across an actual case of a nuclear power plant closure following the events of 9/11, the physical integrity of nuclear power plants has been questioned in a number of countries, as evidenced by the two studies from Germany and Switzerland presented in this paper (see section 5.3.1.).

Having laid out the general limitations to the scope of this study, it will now discuss the specific strengths and weaknesses of each chapter in turn.

Chapter 3 provided a comprehensive literature review on the economics of nuclear power and on radioactive waste management. Additionally, where possible ad-hoc consultation with experts across the field provided further insight. As there is a significant amount of literature in these areas, it is felt that this provided a solid basis to identify those issues that could impinge on the nuclear option in the UK. However, time and resource constraints did not allow a more detailed investigation into a number of areas.

Specifically, in the economics section 3.2, it would have been useful to model in more detail the cost implications of some of the policy options outlined, given their central role in opening the nuclear option. Pearson and Peña-Torres (2000) produced, on the basis of cost data from the DTI Nuclear Review (1994), an estimation of the carbon tax needed to equalise the electricity costs between nuclear power and CCGT plants. Given the updated cost estimations for nuclear reactors from BNFL (2002) and current gas price forecasts a similar exercise could be undertaken to put a price tag to some of today's policy options. Furthermore, the topic of new reactor designs, such as those currently envisaged in the Generation IV international research programme could alter the economic assumptions underlying nuclear reactors again. As indicated, the liberalized market structure in the UK favours technologies with short lead-times and low up-front capital intensity. If these criteria could be met with new reactor designs, an important obstacle to the nuclear option in the UK would be mitigated. Here, more detailed comparisons with cost estimates of other electricity technologies would have allowed to state more specifically the cost ranges that would be competitive for new reactor designs.

On radioactive waste, the crucial role of a consultation process that finds a publicly acceptable radioactive waste management strategy was emphasized in section 3.3. However, due to time constraints, the different options on public consultation could not be discussed in more detail. It will be an important task, especially for the newly founded Committee on Radioactive Waste Management (CoRWM) to review the experience from the public inquiry on Nirex's application from 1994 to1996 and establish a clear strategy forward. This will also serve to clarify the timeframe within which a solution will be arrived at, a factor central to keeping the nuclear option open in the UK. In this relation, a further aspect not considered in this study, are the successful public deliberation processes in Finland and Sweden to identify a publicly acceptable radioactive waste management options. Further research could identify aspects from these examples that would also be applicable to the UK.

Chapter 4 analysed whether a nuclear skills shortage could affect the UK's ability to keep the nuclear option open. The main sources of information were a series of semi-structured interviews. As outlined in the Methodology in section 2.2.1, a factor that could not be ruled out in the interviews was that of bias. Given the historic close links between different stakeholders of the nuclear industry and the current *de-facto* government ownership of both BNFL and BE, the results are likely to be skewed towards the interest of the nuclear industry. Also, time and resource constraints prohibited a further probing of the results obtained. Wider consultation and peer review at all stages of the research would have been welcome.

However, it was felt that the research approach taken was still able to reveal the most important issues in relation to the topic, and that the issue of bias mostly impacted on the question of the level of government support needed in the area. Consequently, rather than making specific policy recommendations, Textbox 4 outlined a range of question that could support a decision-making process in this area. One field for further research could be to pin down further the specific skill requirements for the nuclear option together with associated learning pathways and timescales needed to (re-)generate them. Similarly, UK research policy in the nuclear area and the distribution of funding obligation seems in need of more strategic oversight and could be put under review. Recommendations in this respect will be outlined in the next section 6.2.

Chapter 5 on the safety and security implications of recent terrorist events was only able to draw on a limited number of sources. As acknowledged before, security and confidentiality considerations as well as time and resource constraints to follow up existing and to pursue additional contacts limited the amount of information that could be collected. Some contacts refused to comment on the issues raised. In the light of these problems, results in this chapter rather point to areas of concern than provide a full discussion. The question of economic impacts on nuclear power as a consequence of recent terrorist attacks remains ultimately unresolved. However, a key area for further research is the relation of confidentiality, public trust and their impact on the decision-making process for nuclear power. How would a public enquiry, an integral part of the planning process, address this problem? Scenarios could be imagined where a planning officer or nuclear inspector would be under pressure to mandate ‘visible’ safety measures to a nuclear power plant in order to compensate for the ‘invisibility’ of those measures that are covered by security and thus confidentiality concerns. The impact on nuclear costs of such a scenario could be significant, as indicated by the statement of Floyd (NEI) in section 5.3.1. A more fundamental concern arising out of this chapter is the question of what would happen to the nuclear option if the physical integrity of existing (older) plants would be tested by a real terrorist event, or even an attempted terrorist act. It is possible that, whatever the actual damage and radioactive release would be, the nuclear option in the UK would be closed politically after such an event.

In summary, there are a number of areas for further research. On the economics of nuclear power it would be desirable to price more explicitly the policy measures needed to support nuclear power. For the area of radioactive waste management, more research in the effectiveness of various processes of public consultation could aid the policy-making process. In this context, Finland and Sweden could provide insightful case studies. Chapter 4 outlined the need for a clarification of strategy in the nuclear research and development area. Key questions that have to be answered include the scope, nature and timeframe of research that merits government support. Finally, the changing safety and security environment following recent terrorist events not only necessitates research into the physical integrity of nuclear power plants. From a public policy point of view the relation of confidentiality, public trust and their impact on the decision-making process for nuclear power is in need of further analysis.

6.2. Conclusion

As mentioned in the introduction in chapter 1, there were two timeframes that were seen as relevant to this study. Firstly, the ability of the UK to keep the nuclear option open in the short term with a perspective to the energy policy review proposed for 2005/2006. Secondly, the long-term option towards the year 2020 when radical new technologies could become available.

6.2.1. The short-term timeframe

With respect to the short-term timeframe, it appears from the findings in this study that the two most important sectors for government activity would be economics and waste. While the skill base would be little changed in such a short-term timeframe, the area of safety and security would not require active change from its current level.

In order to facilitate new nuclear build within this timeframe, government intervention would have to be considered to make the cost-profile of nuclear power competitive. The various policy options have been outlined in section 3.2.6. As mentioned in the previous section, one area for further research could be to carry out more detailed costing studies of the various policy options as has been done in the USA (Holt and Parker 2003). Pearson and Pena-Torres

(2000) derived, albeit on the basis of old cost data, a carbon tax necessary to make nuclear cost competitive with CCGT plants in the UK. These results pointed towards significant economic costs of a policy intervention.

Radioactive waste management could potentially be the biggest obstacle to the nuclear option in the short-term. It seems important that, at a minimum, a publicly acceptable option is found before new nuclear build would start. The evidence presented in this paper suggests that the issues of nuclear power and radioactive waste are inextricably linked in the public's mind, even if, as representatives of the industry point out, the waste arisings of new nuclear power stations are very small compared to the legacy waste. The timeframe that such a process can take place in is likely to go beyond 2005/2006 and there is likely to be a trade-off between the speed with which a decision on radioactive waste is made and the public acceptability of such a decision.

The most important factor in relation to skills is the uncertainty associated with the government policy of keeping the option open. This, however, is less a factor in the short-term. Should there be a government decision in 2005/2006 to support new nuclear build, this would send a strong signal to graduates considering their options upon leaving university. Furthermore, this would give planning certainty to the industry more generally and pave the way for additional resources to the NII to carry out the necessary pre-licensing review of new designs. The question of additional research funding by the government would then be less urgent and the questions outlined in Textbox 4 earlier would likely be interpreted narrowly.

In the area of safety and security, one potential obstacle to the nuclear option was identified as the public acceptability of nuclear power as a consequence of the need for confidentiality in the security environment following 9/11. Although no definitive statements can be made in this area, one suggestion that followed from the discussion in chapter 5 was for the industry to engage more actively, and, more importantly, openly, in stakeholder dialogues to address some of the fears expressed in the public.

6.2.2. The long-term timeframe

As outlined in the previous section, keeping the nuclear option open in the short-term is likely to entail significant costs, financial and political. Although it is of course speculative to sketch out a long-term perspective for the nuclear option towards a time window of around 2020, some real differences between the two scenarios can be identified.

It was outlined in the introduction that the Generation IV international research project could be an opportunity to address some of the concerns raised so far. Although still at an infant stage, its "Technology Roadmap" (Generation IV 2003) points to some promising developments. Significantly, with respects to the economics, there are a number of reactor designs proposed that aim at smaller units and modular construction. This trend would address some of the risks outlined in section 3.2. such as the construction lead-time, investment payback time and more generally, the effects of the discount rate.

Significantly, for the long-term nuclear option, it is likely that the consultation process on radioactive waste management options has made progress. Although it can only be speculated about the results, it would definitely give the nuclear industry a time window to engage with the public especially on the points of lack of trust and perceived lack of transparency.

With respects to the nuclear skill base, in the absence of government commitment to new build, the industry will increasingly focus on those parts that are viable in their own right, most likely to be dominated by decommissioning and waste management. This would increase the need for government support to those parts of the nuclear skill base that are vital to the nuclear energy option in the UK. Generally, chapter 4 made a case for some form of involvement in nuclear R&D funding. Textbox 4 outlined a number of issues that have to be considered with respect to the scale, scope and nature of the support needed. It is reproduced again on the next page as Textbox 6 for ease of reference. A further issue in this respect is the coordination and strategic collaboration in research. The government will have to clarify its strategy and engage with the research councils, regulators and the industry in this area. These measures become more relevant should the decline in the number of engineering and science graduates, as identified in the 'Roberts Review' (HMT 2002) continue.

Textbox 6 – policy options for government support of R&D

- Extent of government support (near market/ blue skies)
- Scope of government support (reactor design/safety/waste)
- Type of government support (direct/indirect)
- Nature of government support (grant/tax credit/in-kind)
- Duration of government support (start-up/on-going/long-term)

To speculate about the safety and security environment and its impact on the nuclear option in the year 2020 would be beyond the scope of this paper. Reference will again be made to the Generation IV programme and its remit to incorporate the recent changes in the threat environment into new designs.

6.3. Further Issues

In the light of the above discussion it seems that there is a difficult trade-off for government if it wants to keep the nuclear option open. In the short-term it is likely that it has to invest significant financial and political capital to promote new build. The long-term bears a host of uncertainties albeit some of the short-term problems might be resolved. In the following a number of further issues are set out which consider some of the points raised throughout this paper.

Apart from market liberalization, one reason why the economics of nuclear power are relatively unfavourable today is the fact that even the new (passive) designs are based on old technology. Inside the new advanced passive safety features of the BNFL AP1000 is essentially the same old PWR process that was first built in the 1970s in the USA. The design process of nuclear power plants over the last 30 years has essentially been an evolutionary one with a focus on improved safety performance and exploiting economies of scale. This is reflected, for example, in one paper by Kouvaritakis et al. (2000) in a low technological learning curve relative to other energy technologies. One reason for the optimism on the Generation IV research project is the fact, that this actually allows the investigation of some radically new designs, which could potentially avoid some of the cul-de-sacs that current evolutionary design has got caught in.

A recurrent theme in this paper was the lack of public trust in and the perceived lack of transparency and openness of the nuclear industry. Suggestions about stakeholder consultations and trust building exercises have been made, although they have not been specified further. In fact, BNFL already has a stakeholder engagement programme and has now even produced its first ever CSR report. However, to quote Dr. Hunt again: “Institutions have to listen!” All these processes can only be effective if communication is two-way and one side does not just try to persuade the other side of its view. In this respect, Nirex is actually a good example for the transformation of a nuclear company. With the expected change in ownership structure and complete overhaul of its activities it has actually undergone institutional change to respond to concerns raised in the public. It could be asked whether similar fundamental processes are necessary for BNFL and BE as well. This point is all the more relevant as currently the government is still the owner of BNFL and is also de facto in control over BE’s future.

To put the discussion on the UK nuclear skill base into perspective, the USA has actually retained its nuclear skill base although no new nuclear power plant was ordered there for nearly 25 years (Heppenheimer 2002:46). Furthermore, countries like China and India have built up their own nuclear skill base from scratch, albeit at a cost and over a substantial timeframe. In this light, various comments received during the research that alleged the UK nuclear skill base would essentially dry up in the absence of new nuclear reactor programmes seem vastly pessimistic and self-serving. Given adequate government support and strategic oversight over those areas relevant to a country’s nuclear policy, it seems unlikely that a country will really shut its nuclear option on the basis of a missing skill base. Rather, it is a question of timing and costs of providing the skill base for when it is needed.

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Appendix 1

List of meetings attended in the initial research period:

20 May 2003, Royal Institution, Panel Debate: 'Nuclear power: Global-warming escape or unnecessary risk?' with Ian Fells, Emeritus Professor of Energy Conversion at the University of Newcastle upon Tyne, Mark Johnston, former staff member and energy specialist at both Friends of the Earth (FoE) and Greenpeace, Bruno Lescoeur, Director of Energy at Éléctricité de France, Vladimir Berkovski, Deputy Director of the Radiation Protection Institute in Kiev (the nearest city to Chernobyl).

27 May 2003, Institute of Physics, 'Nuclear Briefing Seminar: Energy Sustainability', with Terry Jackson, Chair, IoP Energy Management Group, Dr Richard Mayson, Director of Reactor Systems, BNFL, Bertrand Barre, Director of Research and Development, Cogema, France, Dr Feroze Duggan, Committee Energy Management Group, Professor Michael Laughton, Imperial College Centre for Energy Policy

12 June 2003, Church House, Nuclear Industry Association (NIA), Annual Symposium for Members of Parliament with presentations by Tony Cooper, chairman NIA, David Drew, MP, Dr. Ian Gibson, MP, Professor Tony Goddard, Imperial College, Dr. Ralph Bennet, Technical Director of Systems Analysis Generation IV programme, Richard Mayon, BNFL

26 June 2003, Institute of Physics, Seminar: 'Nuclear Power: Keeping the Option open', with presentations by Richard Mayson, BNFL, Gordon MacKerron, NERA, Eur Ing Ann McCall, Nirex, and Jane Nicholson, EPSRC. Chaired by Sir Eric Ash, Hydroventuri Ltd

8 July 2003, House of Commons/Palace of Westminster, All Party Parliamentary Group on Nuclear Energy with a presentation by Alan Edwards, Liabilities Management Unit, DTI

Appendix 2

List of people consulted on specific topics for chapter 3:

Robert Loux, Director of the State of Nevada's Nuclear Waste Project Office, email 3 June 2003

Gordon MacKerron, Associate Director, NERA, meeting 17 July 2003

Richard Mayson, Technology Director for Reactor Systems, BNFL, meeting 4 June

Bruce McKirdy, Safety Manager, Nirex, meeting 24 June 2003

Appendix 3

(*all data from the US Department of Energy (DoE) www.doe.gov*)

In the USA, a levy of 0.1$c/kWh is charged on nuclear electricity to cover the total costs of any expected waste management route. This levy is expected to generate an income of about $35bn to $38bn at current projections of lifetimes of existing nuclear power plants, assuming no new build. The current stock of nuclear reactors in the US is rated at about 98,500 MWe. Capacity factors of nuclear power plants have improved dramatically since the levy was introduced in 1983 with the enactment of the Nuclear Waste Policy Act (NWPA),
and construction projects with long delays were finished subsequently. Thus, it can be assumed, that current estimates of total revenue generated from the levy lie at the top end of what could have been expected at the time of the introduction of the levy. Consequently, the $35bn to $38bn provide an upper boundary of the then estimate of total life time income from the levy.

For the exemplary calculation, some abstractions have to be made from the available US figures. The point of the calculation is to show the effect of an unexpected increase in the waste management costs such as might be currently witnessed in the USA. For the ease of argument, it will be assumed that the total stock of 98,500 Mwe of nuclear reactors was *planned* at the same time, and that all plants had the same lifetime of fourty years and a lifetime capacity factor of 80%. Assuming that waste management costs are proportional to electricity output, every company had to contribute to the waste management fund according to its output and make provisions in its cost calculations. Unexpected fluctuations in output and outages are ignored for a moment. Finally, it is assumed that at the beginning of this programme the waste management costs were estimated to be a total of $35bn, and that the annual income from the levy would be spent entirely each year to design, build and finally operate the waste management facility – thus ignoring interest rate and discounting effects for the moment.

It is now assumed that a 1100 MWe reactor with an 80% lifetime capacity factor and 40 year lifetime was built as part of the current stock and calculated to contribute to the waste management fund accordingly. Combining the 80% capacity factor with the 1100MWe rated output of the single plant, the annual output of the plant would be 7,708,800 MWh. Combining the 80% capacity factor with the 98,500 MWe rated capacity of the total stock gives an annual electricity output of 690,388,000 MWh. Thus, the individual plant has a 1.1% share of total output and consequently a 1.1% share of the total back-end costs of $35bn, i.e. $385m. Levelized over the lifetime output of the plant, this share of back-end costs converts to a levy of 0.124$c/kWh.

If it is now assumed that the actual total costs of the waste facility is $100bn, there could be two different effects, depending on when the costs were estimated. If it is assumed that the cost projections were made at the start of the nuclear power plant project, then they could be fully included in the LUC of a nuclear power plant. The 1.1% share of $100bn translates to $1.1bn and levelizing this over the lifetime output of the plant gives levelized back-end costs of 0.357 $c/kWh. This is already a near triplication of the back-end costs. However, they were included in the initial costing of the plant and it could thus be decided before construction whether they threatened the viability of the project or not.

If it is now assumed that the cost increase from $35bn to $100bn is only corrected, say, halfway through the lifetime of a nuclear power plant, the calculations would be different. In the first twenty years of the nuclear plant, a levy of 0.124$c/kWh is charged, corresponding to the initial $35bn cost assumption. This would build up a total of about $191.2m within that timeframe. However, the amount it needs at the end of the plant's life is $1.1bn, not the

$385m that were originally saved for. This means that in the last twenty years a shortfall of $908.8m has to be made up for. Levelizing this amount over the output of the remaining twenty years yields a levy of 0.59$c/kWh, almost five times the original charge. Moreover, this increase in the levy is unexpected and not accounted for before.

Appendix 4

(all descriptions from Nirex 2003)

High-level waste (HLW) is waste in which the temperature may rise significantly as a result of its radioactivity, so this factor has to be taken into account in the design of storage or disposal facilities. Liquid HLW in the form of nitric acid solutions containing fission products, arises from reprocessing irradiated nuclear fuels.

Intermediate-level waste (ILW) has lower levels of radioactivity than HLW and does not need heat to be taken into account in the design of storage or disposal facilities. Not every facility that handles nuclear material will generate ILW. Typically, ILW consists of chemical sludges, filters, components from inside nuclear reactors, radioactive sources used in medicine or research and development apparatus.

Low-level waste (LLW) offers a much lower potential hazard than other categories, but because it still contains some radioactive material it is not acceptable for disposal as ordinary refuse. It usually consists of contaminated equipment and protective clothing from facilities that handle nuclear material, or contaminated materials such as concrete rubble.