Parliamentary Office of
Science and Technology

Assessing the risk of terrorist attacks on nuclear facilities

July 2004
Report 222

Summary

The events of September 11th 2001 heightened concerns over the potential for terrorist attacks on nuclear facilities. The purpose of this report is to provide Parliamentarians with an overview of what is publicly known about the risks and the consequences of such an attack, either at a facility in the UK, or overseas, with very direct impacts in the UK. This report identifies the main issues of concern according to reports in the public domain, and highlights areas where understanding is limited due to lack of publicly available information.

The key points made in this report are as follows:

- There is sufficient information in the public domain to identify possible ways terrorists might bring about a release of radioactive material from a nuclear facility. However this information is not sufficient to draw conclusions on the likelihood of a successful attack, or the size and nature of any release.
- After September 11th 2001 additional protection measures have been put in place to increase security and to strengthen emergency planning at and around nuclear facilities. However, full details are not in the public domain.
- Nuclear power plants were not designed to withstand some forms of terrorist attack, such as large aircraft impact, but existing safety and security regimes provide some defence.
- Published reports suggest that, in a worst case scenario, the impact of large aircraft on certain facilities could cause a significant release of radioactive material with effects over a wide area. However, some analysts question the accuracy of these reports, and argue that accurately targeting these facilities would be difficult.
- A successful attack would be highly unlikely to cause large numbers of instant fatalities. Although it would have the potential to affect extensive areas of land and cause large numbers of cancers, its impact would depend on how effectively appropriate contingency plans were implemented.
- Even an unsuccessful attack could have economic and social repercussions and affect public confidence in nuclear activities such as power generation.
- Published reports draw widely different conclusions about the consequences of attacks on nuclear facilities, due to differing assumptions about the size and nature of the release, weather conditions and efficiency of countermeasures.
- Media coverage of the risk of releases of radioactive material from nuclear facilities focuses mainly on the consequences of worst case scenarios, without discussing the likelihood of their occurrence or explaining assumptions made.
- Analyses carried out by UK nuclear operators to investigate the consequences of accidents at nuclear plants could be used to further understanding of the potential consequences of terrorist attacks. However these analyses are largely not publicly available. The scope of further work would be limited without such information.

A four page summary of this report is available from POST, or on www.parliament.uk/post

Contents

1 Introduction 1
1.1 Background to this report 1
1.2 Objectives of the report 1
1.3 Structure of the report 2

2 Types of nuclear facility 4
2.1 Introduction 4
2.2 Types of activity 4
Civilian nuclear power 5
Research reactors 5
Uses of radioactive material 6
Military activities 6
Radioactive waste 8
Transport 8
2.3 Overview of nuclear activities in the UK 8
Civilian nuclear power 8
Other civilian activities 11
Military activities 11

3 Regulation of nuclear activities 14
3.1 Key points 14
3.2 Introduction 14
3.3 Causes of exposure to ionising radiation 14
3.4 Safety regulation in the UK 14
Safety Assessment Principles for nuclear plants 16
3.5 Environmental regulation 16
3.6 Security regulation 17
3.7 Security arrangements at civilian nuclear facilities 17
Physical protection of nuclear facilities 17
Non-proliferation 17
3.8 The Office for Civil Nuclear Security (OCNS) 19
Interface between regulators 19
3.9 Security arrangements at military facilities 19

4 Vulnerability assessments part 1: the nature of the threat 21
4.1 Key points 21
4.2 Introduction 21
4.3 The current threat of sabotage 21
4.4 Intelligence reporting within government 22
4.5 Potential modes of attack 23
The Design Basis Threat 23
Other scenarios 24
Attack during transport 25

5 Vulnerability assessments part 2: physical robustness 26
5.1 Key points 26
5.2 Introduction 26
5.3 Engineering principles for nuclear plants 26
5.4 Classification of accidents at nuclear plants 28
5.5 Safety provisions and the terrorist threat 29

Frequency of occurrence 30

6 Vulnerability assessments part 3: security arrangements 31
6.1 Key points 31
6.2 Introduction 31
6.3 Guarding of nuclear sites 31
6.4 Changes made since September 11th 2001 33
Information in the public domain 34
6.5 External assistance 35
6.6 Security at civil nuclear sites in France 37
6.7 Security of civilian nuclear activities relative to other industries 37

7 Vulnerability part 4: evaluating the consequences 39
7.1 Key points 39
7.2 Introduction 39
7.3 Health hazards associated with radioactive materials 39
The biological effects of ionising radiation 39
7.4 Pathways for exposure of people to radiation 41
Environmental dispersion of radionuclides 41
Modes of exposure 43
7.5 Protecting the public in the event of a radioactive release 43
7.6 Modelling the consequences of a release 46

8 Reactors 49
8.1 Key points 49
8.2 Introduction 49
8.3 Nuclear reactors - background 50
How power reactors work 50
Buildings at a nuclear power plant 51
8.4 Reactor safety 51
Controlling the reaction 51
Cooling the reactor core 51
Containing radioactive material 51
8.5 Reactor designs 52
Nuclear reactors worldwide 52
Power plants in the UK 52
8.6 Accidents at nuclear reactors 55
Examples of accidents at nuclear reactors 56
8.7 Terrorist attacks at nuclear reactors 57
Studies in the public domain 58
Aircraft impact 58
Vehicle bombs 61
Ground-based attack 62
Attacks using Liquid Natural Gas or Liquefied Petroleum Gas tanker ships 62
Other modes of attack 63
8.8 Research reactors 64
8.9 Consequences of a release from a nuclear reactor 65
Characteristics of release 65
8.10 Case studies 66
Modelling studies – Sizewell B 66
Data from the Chernobyl accident 67
8.11 Spent fuel storage 70
Security issues associated with spent fuel storage 70

Vulnerability of UK facilities 72
Consequences of an attack on a spent fuel cooling pond 73

9 Reprocessing plants 74
9.1 Key points 74
9.2 Introduction 74
9.3 Background 75
9.4 Sellafield 76
Main activities 76
Terrorist threat 77
9.5 High level liquid waste (HLLW) at Sellafield 78
Safety issues 78
Terrorist attacks 79
Consequences of a release 80
9.6 Plutonium 81
9.7 Other facilities 82
9.8 Emergency planning at Sellafield 83
9.9 Dounreay 85
Activities 85
Safety 85
Radioactive material on the Dounreay site 86
9.10 Cap de la Hague 86
Vulnerability assessments 87
9.11 Issues 87
International variations in policy on reprocessing and spent fuel management 87
Future radioactive waste management options in the UK 87
Policy developments 88

10 Transport of radioactive material 90
10.1 Key points 90
10.2 Introduction 90
10.3 Regulation of transport of radioactive material 90
Safety regulations 91
Security regulations 92
Types of security risk 93
10.4 Case studies 94
10.5 Transport of spent nuclear fuel 96
Design of flasks 96
Risk assessments in the public domain 97
10.6 Transport of separated plutonium 99
Terrorist threat 100
10.7 Transport of nuclear weapons 100
10.8 Transport by sea 101
10.9 Limitations of public domain information 103

11 Contingency Planning 104
11.1 Key points 104
11.2 Introduction 104
11.3 Organisation of emergency management within government 106
11.4 On-site emergency management 106
Preparation 106
Initial Response 106
11.5 Off-site emergency management - local level 108

Preparedness 109
Initial Response to off-site emergencies 113
Recovery following a release of radioactive material 114
11.6 Regional level 115
11.7 National level response 115
Preparation 115
Initial response 117
11.8 International arrangements 118
Preparation 118
Initial response 118
11.9 Releases during transport 119

12 Conclusions 120

13 Annexes 122

14 Glossary and Abbreviations 135

Boxes

Box 2-1 Radioactive, fissile and nuclear materials 4
Box 2-2 Uses of radioactive material 5
Box 2-3 Nuclear facilities in France and Belgium 9
Box 2-4 Classification of radioactive waste 10
Box 2-5 Organisation of nuclear activities in the UK 13
Box 3-1 The principles of radiological risk assessment in the UK 15
Box 3-2 IAEA guidelines on Physical Protection of Nuclear Material and Nuclear Facilities 18
Box 3-3 The Office for Civil Nuclear Security (OCNS) 20
Box 4-1 The Design Basis Threat at US civilian facilities 24
Box 5-1 Aircraft impact 27
Box 6-1 The United Kingdom Atomic Energy Constabulary (AEAC) 32
Box 6-2 Armed response at nuclear facilities in the US 33
Box 6-3 BNFL National Stakeholder Dialogue 35
Box 6-4 UK Air Defence 36
Box 6-5 Security at civil nuclear sites in France 38
Box 7-1 Measuring radiation effects on the human body 40
Box 7-2 Available evidence on cancer risk from ionising radiation 41
Box 7-3 Properties of key radionuclides associated with nuclear fission 45
Box 7-4 Emergency reference levels (ERLs) 46
Box 7-5 The COSYMA model for predicting the radiological consequences of a release 47
Box 8-1 Nuclear reactors 53
Box 8-2 Severe accidents at PWRs and gas-cooled reactors 56
Box 8-3 Examples of accidents at nuclear reactors 57
Box 8-4 Overseas studies on the vulnerability of nuclear power plants to aircraft attack 60
Box 8-5 Silwood Park research reactor 65
Box 8-6 Fission product dispersal 66
Box 8-7 Spent fuel storage facilities in the UK 71
Box 9-1 Reprocessing techniques 75
Box 9-2 Radioactive waste at Sellafield 77
Box 9-3 Examples of changes made at Sellafield since September 11th 2001 85
Box 10-1 IAEA requirements for physical protection of nuclear material during transport 93
Box 10-2 Theft of a nuclear weapon or radioactive material 94
Box 10-3 Types of shipment and discussion of risk 95
Box 10-4 Overseas studies of spent fuel transport 98
Box 10-5 Transport of spent nuclear fuel through London 99
Box 11-1 CBRN emergency planning : who's who within government 105
Box 11-2 Emergency exercises 107
Box 11-3 Dose limits for workers 108
Box 11-4 Radiation Emergency Preparedness and Public Information Regulations 109
Box 11-5 The Civil Contingencies Bill 110
Box 11-6 Survey of corporate sector preparedness for acts of terrorism 112
Box 11-7 The National Steering Committee on Warning and Informing the Public 114
Box 11-8 Environmental decontamination and clean-up following radiological releases 116
Box 11-9 Lead Government Departments 117
Box 13-1 Radioactivity and ionising radiation 122
Box 13-2 Uranium and plutonium 123
Box 13-3 Principles of radiological protection 129

Figures

Figure 2-1 Nuclear power plants in Europe (as of October 2002) 6
Figure 2-2 The nuclear fuel cycle 7
Figure 3-1 The ALARP triangle 16
Figure 5-1 Example of an Event Tree Analysis 29
Figure 7-1 Pathways for exposure to ionising radiation. 44
Figure 8-1 Diagram of a pressurised water reactor (PWR) 54
Figure 8-2 Diagram of an advanced gas-cooled reactor (AGR) 54
Figure 8-3 Artists impression of the ANSTO Replacement Research Reactor 62
Figure 10-1 The radioactive trefoil symbol 91
Figure 10-2 A spent fuel flask 97
Figure 10-3 Purpose built vessel for the transport of spent nuclear fuel. 102
Figure 13-1 Nuclear fission 123
Figure 13-2 Map showing location of nuclear sites in the UK 126
Figure 13-3 Nuclear facilities in France and Belgium 128
Figure 13-4 The International Nuclear Event Scale 130
Figure 13-5 Articles containing keywords 'Sellafield' and 'terrorism' in print media. 133
Figure 13-6 MOX shipment from the UK to Japan (19th July 1999) 134
Figure 13-7 Return MOX shipment from Japan to the UK (17th September 2002) 134

Tables

Table 1 Operational and decommissioning power plants 124
Table 2 Events linked to media coverage of Sellafield 133

1 Introduction

1.1 Background to this report

In July 2002 the House of Commons Defence Select Committee published its report on *'Defence and Security in the UK'*.[1] In this report, the committee examined how the UK was placed to respond to acts of terrorism, considering both protecting against and preventing a terrorist attack, and managing any consequences.

A range of terrorist threats was analysed, including chemical, biological, radiological and nuclear (CBRN). The threat from radiological and nuclear terrorism, which was examined in POSTnote 179, can be broadly divided into three main categories:

- Terrorists detonating nuclear weapons, either by stealing weapons or by stealing nuclear material and constructing their own device.
- Terrorists dispersing radioactive material by means of a 'dirty bomb'.
- Terrorists dispersing radioactive material by means of sabotage of a nuclear installation or a shipment of radioactive materials.

The Select Committee's report pointed out that although some evidence had been received relating to the risks and potential consequences of a terrorist attack on a nuclear installation,[2] the committee had not been able to examine the issue in any detail, and remained concerned by the *'potentially catastrophic consequences of such an attack'.*[3] [4] The committee therefore invited the Board of POST to consider a proposal for an investigation *'examining the physical robustness of nuclear installations against such attacks as well as the potential consequences in terms of the amounts of radioactive material liable to be released and its effects'*. The Board of POST accepted the invitation. This report is the outcome of a study that aims to bring together all the relevant information in the public domain to inform Parliamentary debate.

1.2 Objectives of the report

After the events of September 11th 2001, the debate over the potential risk of terrorist attacks on nuclear facilities has received widespread media coverage, stimulated by a number of reports placed in the public domain both in the UK and overseas. These reports are largely by non-governmental organisations and environmental groups, but also to some extent by the nuclear industry and nuclear regulators. Thus, most publicly available information comes from groups that either have a pro-nuclear or anti-nuclear stance, or are connected with the nuclear industry in some way.

The purpose of POST's report is therefore to provide Parliamentarians with a balanced and impartial overview of what is publicly known about this issue. The report focuses on the risk of sabotage of nuclear installations and shipments of radioactive material, both in the UK and

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[1] Defence Select Committee, 6th report, session 2001-2002, *Defence and Security in the UK*, July 2002.

[2] As explained in the glossary, the term 'nuclear installation' refers specifically to facilities associated with the nuclear fuel cycle, whereas the term 'nuclear facility' is used more broadly to refer to a range of facilities housing radioactive material.

[3] Mr Gordon Thompson, Memorandum submitted to the Defence Select Committee inquiry into *Defence and Security in the UK*, Appendices to the Minutes of Evidence, Appendix 1, 3rd January 2002. Gordon Thompson is Executive Director of IRSS, a US-based NGO (www.irss-usa.org) which has produced a number of reports on safety and security issues at Sellafield and Cap de la Hague, cited elsewhere in this report.

[4] Dr Frank Barnaby, Memorandum submitted to the Defence Select Committee inquiry into *Defence and Security in the UK*, Appendices to the Minutes of Evidence, Appendix 4, February 2002.

overseas, with impacts on the UK. It does not provide a detailed discussion of the risk of theft of radioactive material.

Some reviewers raised concerns that the information in the public domain is inherently biased towards the anti-nuclear movement, as those accountable for security are not permitted to publish full details of their activities or analyses. POST has endeavoured to avoid any bias in this report by consulting widely with a range of parties, including experts from the nuclear industry and regulators, and relevant government departments, as well as from non-governmental organisations and environmental groups.[5]

After September 11th 2001, UK authorities carried out extensive studies to assess the vulnerability of UK nuclear installations to terrorist attack. However, these studies are largely classified, and are therefore not subject to a public peer review process because of their sensitivity. Therefore much of the information required to produce a comprehensive analysis, or to assess statements made by nuclear operators and regulators, lies outside the public domain (although the UK nuclear operators and regulators and other official bodies have assisted POST considerably in the course of this study, by providing access to sensitive inner areas of Sellafield and to classified background briefings). This report highlights areas where understanding is limited due to lack of publicly available information and discusses the extent to which this may influence public perception.

This report does not make recommendations. The aim is to summarise current information and to place the diverse commentary on this issue in context.[6]

1.3 Structure of the report

Chapters 2 to 3 of this report are introductory chapters. Chapter 2 describes the types of activity that involve radioactive material, and the different kinds of facility associated with them. Chapter 3 describes the regulations in place to minimise the risks associated with these activities.

Chapters 4 to 7 outline the four strands to be considered when assessing the threat of sabotage:

- Intelligence - which terrorist groups are operating and which of these groups, if any, have the intention to attack a nuclear installation, and the resources that might be available to them to mount an attack.
- Vulnerability - the physical robustness of the facilities themselves.
- Security - the robustness of security arrangements in place at nuclear facilities.
- Consequences - the potential environmental and health impacts of a release of radioactive material from a nuclear installation, and the extent to which these consequences could be mitigated by contingency planning arrangements, both on-site and off-site.

Although all four factors are equally important, there is limited public information on intelligence information and security regimes. This report therefore focuses on what is stated in public reports about the physical robustness of nuclear facilities and the potential consequences of an attack.

Three types of 'nuclear facility' are then reviewed in more detail: nuclear reactors (Chapter 8); reprocessing plants (Chapter 9) and transport of radioactive material (Chapter 10).[7] In each case,

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[5] At various points in this report, POST has included statements from these parties. It has done so to inform readers and does not necessarily endorse the substance of the statements.

[6] In this report 'commentary' refers not only to official reports but also to reports by NGOs, environmental groups and independent analysts. Media reports are excluded unless explicitly stated.

the report provides some technical background, highlights the main safety features which must be preserved to prevent release of radioactive material, and discusses the extent to which existing safety features provide defence against terrorist attack. Commentary on the degree of damage likely to result from different modes of terrorist attack is reviewed. Chapter 11 then discusses what is known about emergency arrangements for dealing with releases of radioactive or nuclear material, either from fixed installations or during transport. It describes UK arrangements at a local, regional and national level, as well as giving a brief overview of international arrangements.

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[7] For the purposes of this report the term ‘nuclear facility’ is also used to refer to systems for the transport of radioactive material.

2 Types of nuclear facility

2.1 Introduction

This chapter describes the different kinds of activity taking place today involving radioactive materials, and the associated facilities. Section 2.2 provides an general overview, while Section 2.3 provides an overview of activities in the UK. Activities in neighbouring countries are also briefly discussed. A detailed discussion of the properties of radioactive materials is provided in Annex 1. Potential hazards associated with their use are outlined in the next chapter.

2.2 Types of activity

Radioactive, fissile materials and nuclear materials (Box 2-1) have a wide range of civilian and military applications which are discussed below in the following categories:

- Civilian nuclear power.
- Research reactors.
- Use of radioactive materials in medicine, industry and research.
- Military applications - nuclear submarines, and the construction of nuclear weapons.

Most of these applications involve transport of radioactive material, and give rise to radioactive waste, which must be managed. These issues are also discussed.

Box 2-1 Radioactive, fissile and nuclear materials

All matter is made of atoms, consisting of a nucleus (made of positively charged protons and uncharged neutrons) orbited by negatively charged electrons. Different elements have different numbers of protons in their nucleus. **Isotopes** are forms of the same element with the same number of protons but different numbers of neutrons in their nucleus, and therefore different masses. For example, hydrogen has one proton and no neutrons in its nucleus, but there are two other isotopes of hydrogen: deuterium (one proton and one neutron) and tritium (one proton and two neutrons).

Radioactive materials have unstable nuclei that decay by emitting **ionising radiation**, which can strip electrons away from atoms (in a process known as ‘ionisation’). Ionising radiation can damage living tissue and exposure to excess radiation can therefore be harmful to human health. This is discussed further in Chapter 7. A given chemical element can have several different **radioisotopes** (also referred to as radionuclides) with different radioactive properties. Radioactivity has applications in many areas, from radioactive carbon dating to the use of radioactive tracers in medical diagnostics

Some radioactive materials can undergo **nuclear fission**, where heavy atomic nuclei fragment into smaller nuclei, releasing energy and neutrons in the process. These are known as **fissile materials** (certain isotopes of uranium and plutonium). Each fission reaction can initiate further fissions, leading to a self-sustaining **nuclear chain reaction**. When this occurs the reaction is said to have achieved **criticality.** This is the principle behind atomic bombs (where the chain reaction causes an explosive release of energy) and nuclear reactors (where the release of energy is controlled).

Nuclear material is a term used to describe both fissile materials and non-fissile materials which are suitable for transformation into fissile materials. A more detailed discussion of radioactivity and fission is provided in Annex 1.

Units of radioactivity

The **Becquerel (Bq)** is the unit used to describe the radioactivity of radioactive material. Material decaying at the rate of one disintegration per second has an activity of one Bq. This is a very small amount, so units of Tera Bq (10^{12}) and Giga Bq (10^{9}) are commonly used.

Civilian nuclear power

Nuclear reactors were first developed in the 1940s by the USA to make plutonium for use in nuclear weapons. Nowadays however, reactors are primarily used in power plants to produce electricity for civilian purposes. As of March 2004, there are 440 commercial power reactors are in operation in 31 countries worldwide, with 166 in Europe (Figure 2-1).[8] The operation of nuclear reactors involves a range of activities collectively referred to as the 'nuclear fuel cycle', outlined in Figure 2-2. This involves the following key stages, which are described in more detail in subsequent sections:

- **The 'front end' of the cycle** - the mining of uranium ore (which takes place largely in Canada, Australia and Africa) and its subsequent purification, enrichment,[9] and fabrication into fuel elements.
- **The operation of nuclear reactors** - several different designs of power plant are in operation. These are discussed in more detail in Chapter 8.
- **The 'back end' of the fuel cycle** - after ~3-5 years, fuel elements are removed and replaced. This fuel is referred to as 'spent fuel' and can be reprocessed to extract re-usable uranium and plutonium. There are commercial reprocessing plants in the UK, France, Russia and Japan. Spent fuel not destined for reprocessing is held in interim storage pending a decision on its long term management.

Research reactors

There are 284 research reactors in operation in 56 countries.[10] Research reactors operate on a small scale compared with power plants (a few kg of fuel as opposed to several hundred tonnes in a power plant). They are generally used as sources of neutrons (neutral particles) for applications including materials testing and manufacture of radioisotopes for medicine, industry and research. Some research reactors use 'Highly Enriched Uranium' (HEU) which may be suitable for use in nuclear weapons (see Annex 1). Section 8.8 provides further discussion of research reactors and related security issues.

Box 2-2 Uses of radioactive material

- Medicine-Radioisotopes such as caesium-137 (i.e. caesium with 137 protons and neutrons in its nucleus) emit highly energetic gamma rays that destroy living tissue, and can be used in radiotherapy. In medical diagnostics, patients are injected with small quantities of radioisotopes that concentrate in certain parts of the body, which can then be imaged – for example iodine-123, which concentrates in the thyroid gland, is used to detect thyroid disorders.
- Industry- because ionising radiation loses energy as it passes through matter, radionuclides can be used in gauges to measure thickness and density; or to locate leaks (e.g. in pipelines and oil wells). They can also be used to detect toxic fumes (e.g. in smoke detectors).
- Research-examples include radioactive carbon dating and applications in biomedical research and genetics.

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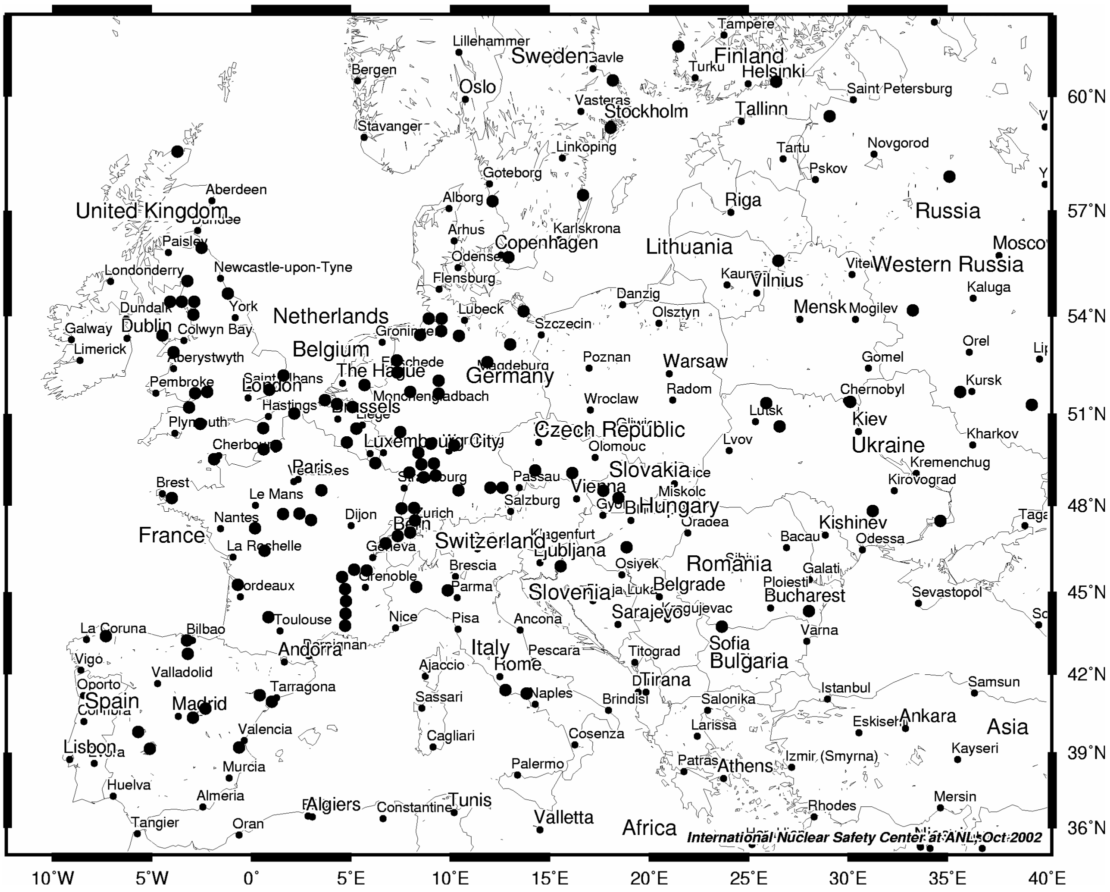
[8] World Nuclear Association, *Nuclear Power in the World Today*, www.world-nuclear.org/info/inf01.htm

[9] Commercial power plants use fuel either based on uranium or on a mixture of uranium or plutonium (an artificial element made from uranium). For most reactors natural uranium must be 'enriched' to increase the proportion of the fissile isotope uranium-235 (U-235), as explained in Annex 1.

[10] World Nuclear Association, *Nuclear Power in the World Today*, www.world-nuclear.org/info/inf01.htm

Figure 2-1 Nuclear power plants in Europe (as of October 2002)



Source: International Nuclear Safety Centre at Argonne National Laboratory. (Large circles indicate nuclear power plants)

Uses of radioactive material

The ionising radiation emitted by radioisotopes (see Annex 1) is useful in a range of medical, industrial and research applications (both civilian and military) outlined in Box 2-2. Radioisotopes are not generally used or stored in quantities comparable with the quantities associated with nuclear power, and are therefore not discussed in detail in this report. The most significant quantities of radioisotopes are handled by the companies in the production chain from initial manufacture to end use in hospitals, universities, etc.

Military activities

Nuclear weapons

The first nuclear weapon was developed by the USA in the 1940s. There are now over 30,000 nuclear weapons in the world (over 90% of which are held by the USA and Russia), as well as stockpiles of plutonium and HEU, which could be used to make weapons (see Annex 1), in over 13 countries.[11]

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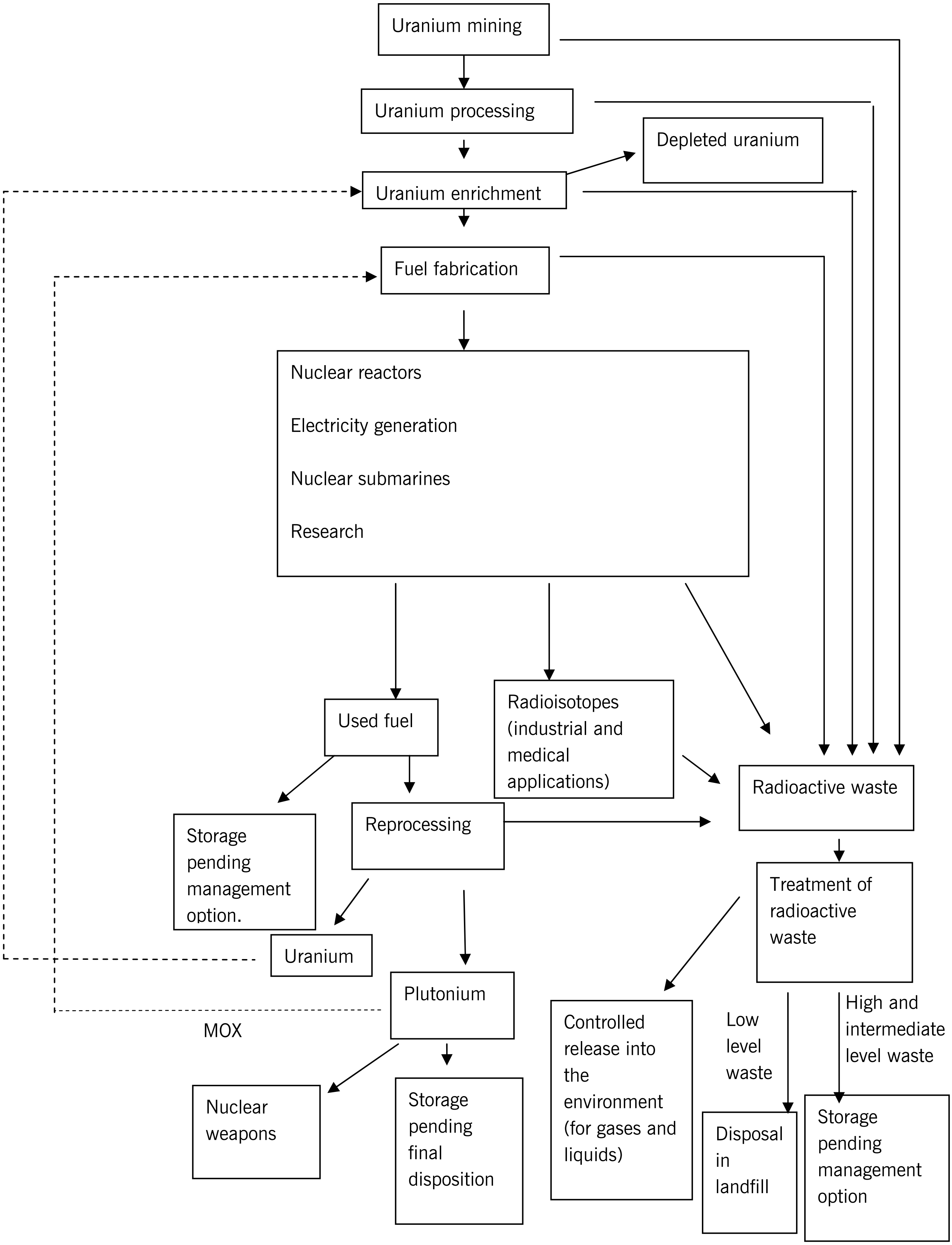
[11] See POSTnote 179 for further discussion about nuclear weapons and their construction.

Figure 2-2 The nuclear fuel cycle



Nuclear powered submarines

There are almost 150 nuclear powered submarines in the world (owned by the USA, UK, France, China and Russia).[12] A range of facilities exists to support them - to make the submarine fuel, to assemble and fit submarine cores, and to carry out maintenance and eventual dismantling. Most countries use HEU to fuel their nuclear powered submarines.[13] These materials are held in military stockpiles.

Radioactive waste

All the above activities generate radioactive waste that must be managed so as to minimise people's exposure to radiation and toxic chemicals (as discussed in the next chapter). Wastes vary considerably in nature and are classified according to various criteria, for example the level of radioactivity and longevity of radioactivity (discussed in Box 2-4). Wastes range from small items of low radioactivity (e.g. contaminated clothes) to highly radioactive liquids from reprocessing, or concrete from decommissioning. Facilities exist for the treatment of radioactive waste, and for its short, medium and long term storage. Many countries have facilities for the disposal of low level radioactive wastes and some for the disposal of intermediate level radioactive wastes. Some countries are developing plans for disposal of higher level wastes in deep geological repositories, but none of these is yet operational.

Transport

Millions of packages containing radioactive or nuclear material are transported worldwide each year, by road, sea, rail or air. Most packages contain very small quantities of radioactive material for medical, industrial or research purposes. However, civilian nuclear power, and defence activities, give rise to a relatively small number of shipments involving larger radioactive inventories. Transport is discussed in more detail in Chapter 10.

2.3 Overview of nuclear activities in the UK

The UK has an extensive civilian nuclear power programme providing one fifth of its electricity. In addition, radioisotopes are used in a range of applications. The UK also maintains a nuclear arsenal and operates nuclear submarines. UK activities are increasingly focussed on decommissioning and management of the wastes generated by earlier programmes. A list and map of UK facilities is provided in Annex 2. An overview of key organisations (nuclear operators, regulators and government departments) is provided in Box 2-5.

Civilian nuclear power

Nuclear power plants

The UK nuclear programme began in the 1940s and was initially focussed on defence applications. However, the use of nuclear reactors as a source of power was achieved as early as 1956 when the military reactors at Calder Hall in Cumbria, were connected to the national grid. The Calder Hall reactors and four sister reactors at Chapelcross were the forerunners of the UK's first commercial nuclear reactors which used the gas-cooled 'Magnox' reactor design (see Box 8-1). The UK constructed a further nine Magnox nuclear power stations in the 1950s, 60s and 70s. These were followed by the construction of seven 'second generation' nuclear power stations using 'Advanced Gas-cooled' reactor (AGR) technology through the 1970s and 1980s. The most recently constructed nuclear reactor in the UK is the Sizewell B pressurised water reactor (PWR) in Suffolk, which started operating in 1995.

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[12] World Nuclear Association, *Nuclear powered ships*, October 2003. http://www.world-nuclear.org/info/inf34.htm

[13] The degree of enrichment varies. See Oxford Research Group, *The Nature of Fissile Materials,* Chapter 3. http://www.oxfordresearchgroup.org.uk/publications/books/handbook/ch3.pdf

Box 2-3 Nuclear facilities in France and Belgium

The closest overseas nuclear facilities to the UK are in France and Belgium (see Figure 2-1). France has 59 operational reactors and obtains over 75% of its electricity from nuclear power. Along its northern coast alone there are 20 reactors in four power plants. There is also a reprocessing facility located at Cap de la Hague. This has facilities for storage and reprocessing of spent fuel and various forms of radioactive waste, as well as for the storage of uranium and plutonium arising from reprocessing. Belgium has a total of seven nuclear reactors at two nuclear power plants and obtains around 60% of its electricity from nuclear power. There are also facilities for fabrication of MOX (mixed oxide) fuel at Dessel.

Today many of the UK's earlier power plants have been shut down. As of July 2004, there are 27 operational reactors at 13 licensed nuclear sites across the UK (5 Magnox, 7 AGR and 1 PWR). Two experimental and prototype reactors at UKAEA's Dounreay site are being decommissioned. There are currently no plans to build new reactors, but it is government policy to keep the nuclear option open. A brief description of nuclear facilities in countries neighbouring the UK is provided in Box 2-3.

Fuel processing and enrichment

At BNFL's Springfields plant in Lancashire, uranium ore is purified and converted, some into uranium tetrafluoride and some into uranium hexafluoride (HEX).[14] The former is used to produce uranium metal for use in Magnox reactors and the latter is sent to Capenhurst in Cheshire, where it is enriched at a facility operated by the trans-national company URENCO.[15] URENCO handles low enriched uranium (LEU) suitable for civil nuclear power plants but not HEU for use in nuclear weapons or submarines. The UK has separate military stockpiles of HEU for such purposes (see next section).

Fuel element fabrication

The enriched HEX is then shipped back to Springfields where it is converted into uranium dioxide before being fabricated into fuel elements (long metal tubes containing uranium fuel). In addition there are facilities at BNFL's Sellafield MOX Plant (SMP) in Cumbria, for fabrication of fuel elements containing Mixed Oxide Fuel (based on both uranium and plutonium oxides) for overseas reactors. Commissioning issues have delayed the MOX fuel manufacture at this facility.[16]

Spent fuel storage facilities

'Wet storage' of spent fuel takes place in cooling ponds at reactor sites in the UK and also at Sellafield (see below). The only dry storage facilities in the UK are short term facilities at the Wylfa Magnox reactor site in Wales. All spent fuel from Magnox and AGR reactors is transported to Sellafield after an initial cooling period of several months. However, spent fuel from Sizewell B PWR is not destined for reprocessing and is held on the reactor site. In the UK, spent fuel from power plants accounts for 99% of the total radioactive inventory transported in the UK each year.

Reprocessing and associated facilities

At BNFL's Sellafield site in Cumbria, there are commercial reprocessing facilities for Magnox and AGR fuel from the UK and for PWR fuel from overseas. There are also treatment and storage facilities for plutonium and uranium from reprocessing, as well as for radioactive waste. Earlier reprocessing facilities at Dounreay in Scotland are being decommissioned. The Sellafield and Cap de la Hague sites hold the two largest inventories of radioactive material in Europe.

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[14] Uranium ore is imported in the form of uranium ore concentrate (UOC) also known as 'yellowcake'.

[15] The UK also imports some of enriched uranium in the form of HEX.

[16] Office for civil Nuclear Security, *The State of Security in the Civil Nuclear Industry*, April 2003-March 2004.

Radioactive waste

In the UK, waste is classified according to its level of radioactivity and the heat it generates (see Box 2-4). The civilian nuclear power industry produces almost 90% of the total volume of waste generated annually in the UK each year.[17] High level waste from reprocessing at Sellafield accounts for over 90% of the total radioactivity of this waste.

Most low level waste is transported from sites where it arises, to the UK's disposal facility at Drigg in Cumbria. Most intermediate and high level wastes are stored at Sellafield. There is currently no long term management strategy for these wastes in the UK, or for spent fuel not destined for reprocessing, and there will not be one for several years.[18]

Box 2-4 Classification of radioactive waste

Radioactivity represents a potential hazard to the environment and to human health. Thus a system is required to grade the degree of hazard associated with different types of radioactive waste, which in turn affects the method of disposal. A number of characteristics can be used to define this hazard:

- The level of radioactivity is the primary characteristic used to define waste.
- The longevity of the waste (i.e. its radioactive half-life as defined in Annex 1). For example some radionuclides such as plutonium-239 have half-lives of thousands of years, while others have half lives of a fraction of a second.
- The type of radiation emitted.
- The heat generated by the waste – this can affect its physical stability.

Different countries have different waste classification systems, which do not necessarily take all these characteristics into account.

Classification in the UK

In the UK, waste is classified by its level of radioactivity and the heat it generates. The categories are:

- Very low level waste (VLLW) covers waste with very low concentrations of radioactivity. It mainly arises from hospitals and non-nuclear industry. VLLW is disposed of by various means, such as with domestic refuse at landfill sites or by incineration, depending on the nature and quantity of the material.
- Low level waste (LLW) - includes metals (redundant equipment) and organic (i.e. carbon-based) materials (e.g. clothing and paper towels). The organic materials mainly come from areas where radioactive materials are used e.g. hospitals and research establishments. Most LLW is disposed of in containers inside a concrete vault at Drigg, near Sellafield, which is operated by BNFL.
- Intermediate level waste (ILW) - consists mainly of metals, with smaller quantities of organic materials, inorganic sludges, cement, graphite, glass and ceramics. ILW mainly arises from the dismantling and reprocessing of spent fuel and from the general operation of nuclear plants.
- High level waste (HLW) - also known as heat-generating waste, consists mainly of concentrated liquid nitric acid product from the reprocessing of spent nuclear fuel.

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[17] NIREX, *Radioactive Wastes in the UK: a Summary of the 2001 Inventory*, October 2002. Civilian nuclear power contributes 87% of the total volume of waste generated annually, research and development contributes 9%, military research 2% and the remainder comes from medical and industrial activities and fuel fabrication.

[18] In 2003 the government set up the Committee on Radioactive Waste Management (CoRWM) to advise on management strategies for the UK's radioactive waste. According to the current timetable CoRWM will make its final recommendations to Ministers in November 2006. See http://www.corwm.org.uk/

Other civilian activities

Research sites

The UK has one operational civilian research reactor belonging to Imperial College (University of London) at Silwood Park in Berkshire. All other civilian research reactors have been decommissioned. Other facilities involved in nuclear research include Culham in Oxfordshire and Daresbury in Cheshire.

Users of radioisotopes

The main distributor of radioisotopes in the UK is Amersham plc (now part of GE Healthcare), which develops and manufactures products containing radioactive materials, such as diagnostic and therapeutic equipment for hospitals. Amersham operate four nuclear licensed sites in the UK[19] and obtain most of their radioactive material from a reactor in Holland.

Military activities[20]

The UK military nuclear programme is overseen by the Ministry of Defence. The main activities are the maintenance of the UK nuclear deterrent, the operation of nuclear submarines and decommissioning of earlier facilities. There are also some sites where military research activities are carried out, and a number of former military research sites which are being decommissioned. No new plutonium or HEU is produced in the UK for military purposes.

Nuclear submarines

All Royal Navy submarines, comprising 4 Trident and a further 11 fleet submarines, are nuclear powered.[21] They use pressurised water reactors (PWRs) which are described in more detail in Chapter 8. The three main UK sites which support submarine activities are Devonport, Rosyth and Faslane. In addition, some development work and training is undertaken at the Vulcan Naval Reactor Test Establishment near Dounreay. Naval nuclear fuel is manufactured by Rolls Royce at Derby and is then transported by road to Devonport for submarine refitting (submarines need refuelling every 5-7 years) and occasionally to Vulcan. New reactor cores are transported to Barrow in Furness (BAE Systems Marine) for installation into new nuclear submarines.

Nuclear weapons

The UK's 4 Trident submarines, each of which can be equipped with up to 48 nuclear warheads, are based at Faslane. The warheads are manufactured at the UK's Atomic Weapons Establishment (AWE) at Aldermaston in Berkshire and assembled at nearby Burghfield. The main nuclear materials used in nuclear weapons are plutonium and HEU. In addition, tritium and depleted uranium (which is a by-product of enrichment) are also used in the production of nuclear weapons. These materials are collectively referred to as special nuclear material (SNM).

Military stockpiles of nuclear and non-nuclear radioactive material

Military stockpiles of plutonium and highly enriched uranium are held at Aldermaston although production of these materials has ceased. The UK has stores of tritium, generated by a tritium extraction plant at Chapelcross[22] and military stores of depleted uranium at Capenhurst.[23]

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[19] At Little Chalfont, Buckinghamshire, Cardiff, and within UKAEA's Harwell site.

[20] Source: www.mod.uk/issues/laesi/section_a.htm

[21] www.royal-navy.mod.uk/static/pages/146.html

[22] William Walker, VERTIC (Verification, Research, Training and Information Centre), *Defence Plutonium Inventories and International Safeguards in the UK*, October 2000.

[23] www.mod.uk/issues/laesi/section_a.htm

Radioactive waste

Apart from some low level radioactive waste suitable for disposal at Drigg, most radioactive waste generated by military activities remains on-site, where it is treated and held in storage pending decisions on its long term management.[24] Spent fuel removed from submarines at Devonport and Rosyth is stored on-site before being transported by rail to Sellafield where it is kept in wet storage. There are currently no plans to reprocess this fuel. Much of the UK's existing waste is 'historic waste' generated from military activities in the 1940s, 50s and 60s. According to Nirex (Box 2-5), historic wastes are *a particular concern* and *may be poorly characterised, chemically degraded and held in old facilities subject to deterioration.*[25]

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[24] www.defra.gov.uk/rwmac/reports/modwaste/08.htm

[25] NIREX, *Radioactive Wastes in the UK: a Summary of the 2001 Inventory*, October 2002

Box 2-5 Organisation of nuclear activities in the UK

Nuclear activities in the UK have seen significant reorganisation since the government's atomic energy programme was first initiated in the 1940s. Nowadays, nuclear sites are managed by a range of nuclear operators, both private and publicly owned. Their activities are overseen by the nuclear regulators, with several government departments and advisory bodies also playing important roles. The responsibilities of some of the main organisations are outlined below.

Nuclear Operators

- United Kingdom Atomic Energy Authority (UKAEA), established in 1954, pioneered the development of nuclear energy in the UK. Activities are now focussed on decommissioning. UKAEA is a public body funded by the Department of Trade and Industry (see below).
- British Nuclear Fuels Plc (BNFL) established in 1971- a public limited company managed on a commercial basis but wholly owned by the government. It provides a range of services to UK and overseas customers (including reprocessing at Sellafield). The UK's Magnox nuclear power plants are operated by Magnox Electric, a subsidiary of BNFL.
- British Energy (BE)- has been wholly in the private sector since 1996. BE owns and operates the UK's 7 AGR nuclear power plants and the UK's only PWR at Sizewell B.
- URENCO Ltd.- A trans-national company mainly involved in uranium enrichment for nuclear fuel and the development of enrichment technologies.

Regulators

- Her Majesty's Nuclear Installations Inspectorate (NII) within the Health and Safety Executive (HSE) is responsible for regulating safety at all UK nuclear sites (both civilian and military) through a system of site licensing.[26]
- Office for Civil Nuclear Security (OCNS) within the Department of Trade and Industry regulates security at all civil nuclear sites. OCNS's role is discussed in more detail in chapter 3.
- Environment Agency regulates environmental impact of nuclear activities in England and Wales. In Scotland activities are regulated by the Scottish Environment Protection Agency (SEPA). In Northern Ireland activities are regulated by the Chief Radio-Chemical Inspector of the Environment and Heritage Service (EHS) Northern Ireland, within the Department of the Environment in Northern Ireland.

Advisory bodies

- UK NIREX Ltd - formed to provide and manage facilities for the safe disposal of radioactive waste in the UK and owned by BNFL, British Energy and UKAEA.
- UK Health Protection Agency (HPA) - formed in April 2003 to provides specialist health advice and support to government, NHS bodies and other stakeholders.
- National Radiological Protection Board (NRPB) - an advisory body established by the Radiological Protection Act of 1970. Gives independent and authoritative advice on radiation protection. The NRPB works in partnership with the HPA.[27]

Government Departments

- Department of Trade and Industry (DTI) - the DTI has a wide range of responsibilities ranging from industry ownership and supervision, to overseeing of certain regulatory activities.
- Department of Food, Environment and Rural Affairs (DEFRA) - leads on radioactive waste issues.
- Department for Transport (DfT) - sets standards for, and approves, shipments of radioactive material.
- Ministry of Defence (MoD)- oversees activities at military nuclear sites, which range from fully 'in house' (i.e. operated by the MoD) to fully privatised.

Responsibilities for emergency management in the event of a release of radioactive material are distributed between various government departments, and are discussed separately in Chapter 11.

Principal source: Department of Trade and Industry, *http://www.dti.gov.uk/energy/nuclear/links/index.shtml*

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[26] Note that some defence activities are exempt from licensing but are internally regulated by MoD regulators.

[27] Primary legislation is planned to incorporate the NRPB into the Health Protection Agency.

3 Regulation of nuclear activities

3.1 Key points

- Regulation of UK nuclear activities is broadly in line with international practice. There are separate regulatory bodies in the UK overseeing safety, security and environmental issues.
- Safety regulation covers all aspects of nuclear activities, ranging from plant siting and design through to eventual decommissioning and the on-site management of radioactive waste. In many cases, safety measures can also increase robustness to terrorist acts.
- Security considerations have not been specifically taken into account in the design of some older civilian nuclear facilities in the UK (e.g. nuclear power plants). However, in the case of facilities constructed over the last 10 years, they have been incorporated into design and are part of the regulatory requirement.

3.2 Introduction

This chapter discusses the regulatory systems in place in the UK to control the risks associated with nuclear activities. Section 3.3 lists the different ways people might be exposed to ionising radiation as a result of these activities. Each of these regulatory systems in place are then discussed: safety regulation (section 3.4), environmental regulation (briefly in section 3.5) and security regulation (sections 3.6 to 3.9).

3.3 Causes of exposure to ionising radiation

Operations involving radioactive materials give rise to ionising radiation, which can be harmful to human health (see section 7.3). Exposure to enhanced levels of ionising radiation could occur for various reasons:

- **Normal operations** could result in exposure of workers. In addition, small quantities of radioactive materials are routinely discharged into the environment.
- **Accidents** - both workers and the public could be exposed in an accident that resulted in dispersal of radioactive material into the environment.
- **Malevolent acts** - workers and the public could be exposed as a result of a terrorist act. For example, terrorists might steal material from a facility to create a nuclear or radiological device, or they might attempt to sabotage a facility to disperse radioactive material.[28]

Regulatory systems, discussed in the next section, are in place in the UK to control these risks.

3.4 Safety regulation in the UK

Within the UK, international requirements to protect people from ionising radiation (see Annex 5) are implemented by the Health and Safety at Work Act 1974 and other relevant statutory provisions.[29] The principles of radiological protection are described in Box 3-1.[30] Under the Nuclear Installations Act, no-one can construct or operate a nuclear installation without a licence.[31] Nuclear site licences are granted by HM Nuclear Installations Inspectorate (NII), which is part of the Health and Safety Executive (HSE). Each site licence has conditions attached, which cover all the activities necessary for the management of safety throughout the life of the

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[28] Note that there is a risk that assemblies of fissile material (e.g. nuclear reactor fuel) could achieve **criticality (**see Box 2-1) as a result of an accident or malevolent act. This could, under very specific circumstances, result in an explosive nuclear reaction. People would then be at risk both from the initial explosion and from the subsequent dispersal of radioactive material.

[29] Including the licensing parts of the Nuclear Installations Act 1965 and the 1993 Radioactive Substances Act.

[30] A description of the HSE's decision making process can be found in the HSE's discussion document *Reducing Risks, Protecting People,* 2001. www.hse.gov.uk/dst/r2p2.pdf

[31] Certain defence activities are exempt from licensing and are internally regulated by MoD Regulators.

plant, from design through to decommissioning. Facilities requiring licences include: nuclear power stations and research reactors, nuclear fuel enrichment and manufacturing facilities, isotope production facilities, nuclear fuel reprocessing pants, radioactive waste treatment and storage facilities, nuclear weapons production and the refuelling of nuclear submarines.

Box 3-1 The principles of radiological risk assessment in the UK

In the UK, the framework for nuclear safety regulation is based on the concept of 'Tolerability of Risk' (ToR), endorsed by the HSE.[32] In this framework, risk can be classified into three categories, which are illustrated in the 'tolerability of risk' or ALARP triangle (Figure 3-1): [33]

- Intolerable – above a certain level risks are not acceptable and cannot be justified except in exceptional circumstances
- Tolerable – in recent years the concept that there is a universally applicable lower bound that defines an acceptable level of risk (which used to be a risk of a fatal cancer of 1 in a million per year) has been replaced by a more sophisticated understanding of risk that judges each case on its merits. Thus, risks that fall below the upper limit are classified as 'tolerable' and can be justified if best efforts are made to reduce the risk to levels that are 'as low as reasonably practicable' (ALARP).
- Broadly acceptable – below a certain level of risk are regarded as insignificant and substantial efforts to reduce them further cannot be justified.

The word 'risk' describes the harm associated with a given activity. However, this can be expressed in many ways - in terms of what could happen (i.e. scenarios), in terms of the likelihood of a given scenario, in terms of its consequences (e.g. the number of fatal cancers) or as a combination of each of these.

A commonly accepted approach is that used by the UK's Health and Safety Executive (HSE). The HSE defines 'risk' and the closely related concept of 'hazard' as follows:

- **Risk** is defined in terms of probabilities or frequencies – i.e. '*the chance of harm being realised*'.
- **Hazard** is defined as '*the intrinsic propensity to cause harm, which would include the magnitude and type of harm as well as the potential for it to be realised.*'[34]

Within this framework, the treatment of 'high risk, low probability' events, i.e. events which are very unlikely to occur but could have very severe consequences, is a contentious issue.

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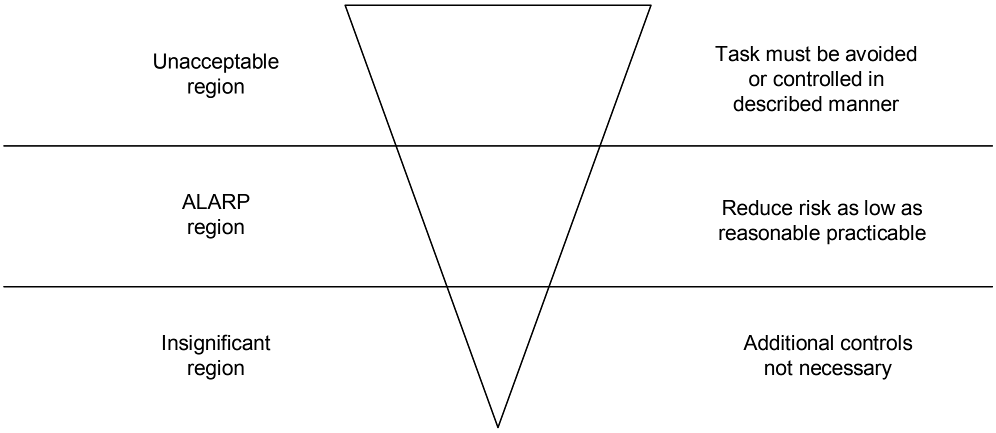
[32] Radiological protection standards in the UK follow principles drawn up by the International Commission on Radiological Protection or ICRP (see Annex 5).

[33] Dr Timothy Walker, Director General, Health and Safety Executive, *Tolerability of risk: its use in Nuclear Regulation in the UK.* www.ilk-online.org/download/en/walker_en.pdf

[34] See footnote 33.

Figure 3-1 The ALARP triangle



Source: Health and Safety Executive

Safety Assessment Principles for nuclear plants

The licensee must produce a 'safety case' for a nuclear plant, to show that it can be designed, constructed, operated, modified and decommissioned safely. The NII inspectors use the NII's safety assessment principles (SAPs) to assess the adequacy of the licensee's safety case.[35] There are 333 SAPs covering nuclear safety which fall into the following categories:[36]

- Fundamental codification of the ICRP principles of radiological protection (Annex 5).
- Safety analysis during normal operation.
- Safety analysis during accident conditions.
- Siting.[37]
- Engineering principles.[38]
- Life-cycle requirements.[39]

These issues are discussed in more detail in Chapter 5, which focuses on the physical robustness of nuclear facilities.

3.5 Environmental regulation

The environmental regulators (Box 2-5) control the discharge of radioactivity to the environment under normal operation, including disposal of solid radioactive waste. Users of radioactive materials cannot discharge radioactive material into the environment without an Authorisation, issued by the relevant environment agency.[40]

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[35] Nuclear Safety Directorate, Health and Safety Executive, *Safety Assessment Principles for Nuclear Plants.*

[36] The NII states that it is currently conducting a major review of its Safety Assessment Principles to ensure they align with the International Atomic Energy Agency's Safety Standards and represent current best international practice.

[37] Siting requirements include consideration of provisions for evacuation and the presence of emergency plans (Chapter 11)

[38] Engineering principles such as inherent safety; failure in a safe manner; passive safety in the event of a failure; defence in depth (see section 5.3).

[39] Life cycle requirements include management system and safety culture, construction, commissioning, maintenance, inspection and testing, decommissioning and accident management.

[40] Under the Radioactive Substances Act 1993.

3.6 Security regulation

Security arrangements for UK nuclear facilities vary depending on whether they are civilian or military and the type of activity. Civilian facilities are regulated by the Office for Civil Nuclear Security (Box 3-3) within the Department of Trade and Industry while security at military sites is regulated by the Ministry of Defence. In general there is less publicly available information for military facilities than for civilian facilities. This section is mainly concerned with civilian facilities as they are the main focus of this report.

3.7 Security arrangements at civilian nuclear facilities

Security at UK civilian nuclear facilities is based closely on international standards. The International Atomic Energy Agency (IAEA) is involved in setting these standards.[41] International standards which affect the security of nuclear facilities fall broadly into two categories: those which specify acceptable security practices relating to physical protection of nuclear material and facilities, and those which specifically aim to combat nuclear proliferation.

Physical protection of nuclear facilities

The physical protection of nuclear material in international transit is covered by the IAEA's Convention on the Physical Protection of Nuclear Material, which came into force in 1987. There are no binding international standards on the domestic use of such material, although some analysts argue that there should be.[42] However the IAEA has issued guidelines on the *Physical Protection of Nuclear Material and Nuclear Facilities* (Box 3-2) which apply to domestic use. These guidelines set out general principles aimed at minimising the risk of theft or sabotage - for example through the use of physical barriers and guards, or through procedures such as access control and security vetting. The guidelines are designed to allow flexibility in their interpretation because of the different needs of different countries. For example, they recommend that nuclear facilities containing 'Category 1' material should be protected by guards (see Box 3-2) but do not specify whether or not the guards on-site should be armed, or how many guards there should be. It is each country's responsibility to ensure that it is adhering to these guidelines - there is no system of international inspection or reporting.

Non-proliferation

The UK is signatory to a number of international treaties which aim to combat nuclear proliferation, such as the Non-Proliferation Treaty[43] and the EURATOM treaty.[44] In order to fulfil its obligations under these treaties, all member states must submit to international safeguards regimes. Safeguards are designed to ensure that nuclear material is not diverted away from its declared end use, into clandestine weapons programmes.

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[41] The IAEA is the main international body with nuclear safety and security expertise. It was set up in 1957 as an independent body within the United Nations to promote peaceful uses of nuclear technology. The IAEA's work includes promoting international safeguards regimes to ensure that nuclear material and activities intended for civilian purposes are not used for military purposes, as well as setting international standards and issuing guidance on a range of issues relating to nuclear safety and security. The IAEA has an extensive programme of work related to nuclear terrorism, which has been considerably expanded since the terrorist attacks of September 11th 2001.

[42] See for example Bunn & Steinhausler, *Guarding nuclear reactors from terrorists and thieves*, Arms Control Today, October 2001. www.armscontrol.org/act/2001_10/bunnoct01.asp

[43] Note that under the NPT the safeguards obligations for Nuclear Weapons States, of which the UK is one, differ from those of the Non Nuclear Weapons States.

[44] The Treaty establishing the European Atomic Energy Community (EURATOM) was signed in Rome in 1957 and is one of the founding treaties of the European Union (EU). The aim of the treaty was to promote the technical development of peaceful uses of nuclear energy across Europe and to ensure security of supply whilst setting standards for the radiation protection of the workforce and the public, and for the safeguarding of nuclear and fissile materials to prevent them from being used for unauthorised military purposes. Note that many NGOs argue that the Euratom Treaty is outdated. See for example http://eu.greenpeace.org/downloads/geneu/PRonEuratom&Convention.pdf

Box 3-2 IAEA guidelines on Physical Protection of Nuclear Material and Nuclear Facilities[45]

The IAEA guidelines on Physical Protection of Nuclear Facilities have been drawn up by experts from a range of IAEA member states, including the UK. They are designed to minimise the opportunities for theft of nuclear material, or sabotage of nuclear facilities. They apply to the use, storage or transport of materials containing fissile isotopes of uranium and plutonium, including spent nuclear fuel. They do not apply to radioactive materials which are not fissile.

Categories of nuclear material

The categorisation of material ranges from category 1, the highest risk, to category 3, the lowest risk. This depends on the type of material, quantity, proportion of fissile material and its physical and chemical form. For example, 5 kg or more of uranium enriched to over 20% (see Annex 1) would be classed as Category 1, while irradiated (spent) nuclear fuel would be Category 2, and natural uranium Category 3.

Principles of physical protection

The guidelines recommend that each country should evaluate the level of threat it faces and produce a document known as a 'Design Basis Threat' (DBT) based on this information. The level of physical protection at a nuclear facility should be adapted to the DBT, and can be achieved in different ways:

- Hardware – e.g. alarms or physical barriers such as security gates and fences.
- Personnel – e.g. the use of guards.
- Procedures – e.g. security vetting, controlling access to the facility. Measures for the protection of computer systems against hacking and other interference are also important.
- Facility design and layout - physical protection should be taken into account as early as possible in the design of the facility.

The specific practical measures recommended by the guidelines vary in different areas of a plant, depending on the kind of material or equipment used or stored there. In order of increasing security, these areas are defined as follows:

- Controlled area: all areas inside the site boundary
- Protected areas: an area within a site containing category 1 or 2 nuclear materials.
- Vital areas: an area located inside a protected area, containing material, equipment, systems, devices whose sabotage could lead to unacceptable radiological consequences.
- Inner areas: an area located inside a protected area where category 1 material is used or stored.

The guidelines make a number of specific recommendations, designed to be flexible to accommodate the different needs of different states. These include:

- Guards: Provision of a 24 hour guard service for all activities involving 'category 1' material; surveillance of inner areas whenever people are in them; patrolling of protected areas. Where guards are not armed, the guidelines say that 'compensating measures' should be applied and that the objective should be the arrival of adequately armed response forces in time to counter armed attacks and prevent the unauthorized removal of nuclear material.
- Access: Minimising the number of access points to the inner and protected areas, searching all people before they enter these areas, and only allowing access to people that are either security vetted or accompanied by a vetted member of staff. Private vehicles should not be allowed inside the inner areas.
- Alarms: provision of systems for detecting intruders and raising alarms, and for communications between guards and a central alarm station.
- Monitoring the use of keys, locks or combinations used to gain access to inner areas.

The guidelines stipulate that the consequences of sabotage should be evaluated, making sure that any measures taken to enhance security do not jeopardise safety. The performance of the physical protection system should be tested at least annually and emergency arrangements should be in place.

Specific guidelines exist for nuclear power plants and for transport of nuclear material (see Chapter 10).

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[45] International Atomic Energy Agency, *The Physical Protection of Nuclear Material and Facilities*, Information Circular 225, 4th revision. www.iaea.org/worldatom/Programmes/Protection/inf225rev4/rev4_content.html

They involve accounting for nuclear material (i.e. declaring stockpiles) as well as submitting to international inspections. Safeguards arrangements are not specifically designed to protect facilities against terrorist acts. However, in many cases, the security arrangements in place for safeguarded material provide additional defence against theft by terrorists. OCNS works closely with the UK safeguards office to maintain standards.

3.8 The Office for Civil Nuclear Security (OCNS)

The Office for Civil Nuclear Security (OCNS) within the Department of Trade and Industry (DTI), was set up to regulate security arrangements at civil nuclear sites. It was originally the security branch of the UKAEA, but was transferred to the DTI in October 2000 in order to avoid a situation where the nuclear security regulator was part of a nuclear operator, itself subject to regulation.[46] The responsibilities of OCNS have broadened since it was first set up, and are outlined in Box 3-3.

Interface between regulators

The IAEA guidelines specify that protection measures against the potential for sabotage of nuclear facilities should be taken in close consultation with safety and physical protection specialists. In the UK, since there are separate bodies overseeing safety (the NII) and security (OCNS), effective regulation depends on good links between them. There is no specific legislation to ensure that the interests of safety and security are balanced but in 2001, OCNS and NII signed a 'Memorandum of Understanding' as a commitment to collaborating on matters which have implications for both safety and security. Similar memoranda have been signed between the NII and the environmental regulator (the Environment Agency).

3.9 Security arrangements at military facilities

Military nuclear facilities are classed as 'military key points', which are sites where security is essential to the 'ability of the country and the armed forces to conduct military operations'.[47] [48] Security arrangements are regulated by the MoD and there is very little detail in the public domain about them.[49] As with civilian nuclear facilities, the nature of the threat that might be faced is summarised in a Design Basis Threat document and security arrangements are in accordance with this DBT.[50] There are different categories of facility depending on the sensitivity of the activity.

It is not possible to draw conclusions on the difference between security at military and at civilian facilities without access to classified information. However, one key difference is that at certain military facilities, defence against hostile acts (i.e. acts of war) has been taken into account in the design of the facility. Another difference is that guarding services are provided by the Ministry of Defence Police (MDP) rather than the UKAEA. The MDP guards AWE Aldermaston, Faslane and Coulport and provides escort of materials in transit. Of the 3,500 MDP, almost 1,200 are employed on nuclear guarding work.

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[46] OCNS is authorised to act as *an independent unit with operational and regulatory autonomy* by DTI Ministers.

[47] The Ministry of Defence also maintains a list of 'economic key point' facilities, the disruption of which would result in serious dislocation of the national infrastructure. Such facilities are protected by the Security Service and arrangements are in place under which the Armed Forces can assist the police to protect them from terrorist attack. Although civilian nuclear installations are not classed as economic key points, OCNS state that 'security levels are comparable in several respects'.

[48] Defence Select Committee, 6th report, session 2001-2002, *Defence and Security in the UK,* July 2002.

[49] Activities involving naval nuclear submarines are regulated by the Naval Nuclear Regulatory Panel, an independent regulator within MoD.

[50] The DBT for military nuclear installations is separate to the DBT for civilian nuclear installations.

Box 3-3 The Office for Civil Nuclear Security (OCNS)

The responsibilities of OCNS have broadened since it was first set up, particularly since the events of September 11th and the introduction of the Anti-Terrorism, Crime and Security Act in 2001. In recent years a number of deficiencies in the civil nuclear security regime have been addressed and improvements are still underway.[51] Under the Nuclear Industries Security Regulations 2003, which came into effect in September 2003, all civil nuclear sites are brought under formal regulation of OCNS. This includes sites handling radioisotopes, operated by Amersham Plc, as well as a number of research establishments. OCNS also directly regulates the transport of nuclear material.[52] The new regulations also include new controls over the disclosure of sensitive information (see Chapter 6). OCNS now regulates security arrangements at 43 civil nuclear sites including 13 nuclear power stations as well as the Sellafield reprocessing complex in Cumbria, the Springfields fuel fabrication plant and the uranium enrichment facility at Capenhurst.

OCNS has four main activities:

- Assessing the threat to nuclear facilities – i.e. putting together the Design Basis Threat, liaising with intelligence agencies and overseas counterparts; assessing *ad hoc* intelligence reports.
- Protection of sensitive material - OCNS also sets standards for the protection of sensitive information on nuclear facilities, which could be of use to terrorists or to countries seeking to develop nuclear weapons; responsibilities also include investigation of breaches and the possibility of instigating criminal prosecutions for unauthorised disclosure of sensitive information.
- Carrying out security vetting for all staff at civil nuclear sites - there are several different levels of security vetting. The basic level of vetting requires checking for previous criminal convictions and may also involve carrying out background enquiries and credit reference checks.
- Reviewing site security plans - under the new regulations, all sites are required to submit a site security plan to OCNS which contains details of security arrangements on-site and demonstrates how the site is protected against attacks specified in the Design Basis Threat (Box 3-2).
- Carrying out inspections at nuclear facilities - inspections were stopped after September 11th 2001 to allow inspectors to concentrate efforts on providing advice to sites on additional security measures. These were resumed in September 2002. They include no-notice inspections, of which 9 were carried out between April 2003-March 2004. Results are not generally made public although OCNS reports that the first no-notice inspection on shipments of radioactive material, carried out by OCNS transport security inspectors, revealed flaws in guarding arrangements (which OCNS reports have since been rectified).[53]

OCNS now has a team of 15 inspectors, most of whom concentrate on-site security, other specialising in transport and information security, policing, guarding and security management. As of June 2004 OCNS had 45 employees with an annual budget of roughly £2.2 million. All operators have their own internal security specialists to oversee the implementation of OCNS's plans – OCNS's role is to provide oversight of security arrangements at these sites rather than to manage them. OCNS is encouraging sites to undertake their own audit programmes, which it may take into account in its inspection process, thus allowing OCNS staff to focus on specific issues and undertake spot checks. Security exercises are carried out to test security arrangements at these facilities, both practical and desktop. However, information on how often these exercises take place, or what lessons have been learned from such exercises, is classified.

Classification of sites and security levels

At any given time security at civil nuclear sites is set according to the current level of alert. In addition, civil nuclear sites in the UK are now classified by OCNS into three categories. The prescribed security measures vary according to the site classification. Sellafield and Dounreay sites are classed as 'high' category. Most other nuclear sites (e.g. nuclear power plants) are classified as 'medium' risk . A small number of sites (e.g. research sites) are classified as 'low' risk and have the least stringent security requirements. As security threats vary with time, security measures at these sites are not constantly maintained at the highest state of readiness. Security measures at these sites are adjusted according to specific threat assessments and alerts issued by OCNS.

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[51] Office for Civil Nuclear Security, *The State of Security in the Civil Nuclear Industry*, Oct. 2000-March 2002, para 59.

[52] OCNS is not responsible for the security of radioactive material held outside licensed nuclear sites, e.g. radiation sources in hospitals, research facilities and industry. Security arrangements for non-nuclear radioactive materials are regulated by Transec, within the Department for Transport.

[53] Office for Civil Nuclear Security, *The State of Security in the Civil Nuclear Industry*, April 2003 - March 2004.

4 Vulnerability assessments part 1: the nature of the threat

4.1 Key points

- The National Commission on Terrorist Attacks upon the United States reports that according to assertions *'reportedly made by various September 11th conspirators and captured Al Qaeda members whilst under interrogation'* nuclear power plants in the United States were among the targets originally considered for the September 11th attacks.
- The UK government's assessment of the threat of CBRN attacks is provided by the Security Service, with support from Defence Intelligence staff. In June 2003 the government set up a Joint Terrorism Analysis Centre in order to improve the quality of intelligence reporting.
- Official information on the potential scale and methods of terrorist attack at civilian nuclear facilities in the UK is contained within a classified document known as the Design Basis Threat (DBT).
- Scenarios suggested in publicly available literature range from ground based attack by a handful of armed intruders to attacks involving hijacked aircraft or gas tankers. However, these are not based on official intelligence information and this report draws no conclusions on whether any of these are currently realistic, or feasible for a terrorist group.
- Surveys of UK print media coverage before and after September 11th 2001 show that public awareness of the terrorist threat to nuclear facilities has greatly increased.

4.2 Introduction

As explained in the introduction, there are four separate factors to be considered when assessing the threat of sabotage of a nuclear facility:

- Intelligence - understanding the nature of the threat – i.e. which terrorist groups are operating and which of these groups, if any, have the intention to attack a nuclear facility, and what resources might be available to them to mount an attack.
- Vulnerability - understanding the physical robustness of the facilities themselves.
- Security - understanding the robustness of security arrangements in place at nuclear facilities.
- Consequences - evaluating the potential environmental and health impacts of a release of radioactive material and the extent to which these consequences would be mitigated by contingency planning arrangements, both on-site and off-site.

This chapter provides a brief discussion of the first factor: the nature of the terrorist threat to nuclear facilities. Section 4.3 provides an overview of current commentary on the actual level of threat faced at nuclear facilities and how this threat has changed since September 11th 2001. Section 4.4 provides an overview of intelligence reporting within government. Section 4.5 discusses potential sabotage scenarios.[54] All the information in this chapter is based primarily on commentary in the public domain rather than on official sources of information. This chapter does not, therefore, attempt to draw conclusions about terrorist intentions.

4.3 The current threat of sabotage

Widespread awareness of the potential terrorist threat to nuclear facilities existed many years before September 11th 2001. In the UK, there were security arrangements in place, largely due to the threat posed by Irish republican terrorist groups. In the US, the Nuclear Regulatory

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[54] A brief discussion of the threat of theft during transport can be found in Chapter 10 section 10.3.

Commission (NRC) took additional measures in the 1990s to protect US nuclear reactors against vehicle bomb attacks following the attack on the World Trade Centre in 1993. Although there have been instances of terrorist groups or individuals threatening to sabotage nuclear reactors, particularly in the former Soviet Union, no recorded incidents have resulted in releases of radioactive material.

Prior to September 11th 2001, the threat of deliberate aircraft impact was not considered likely on the basis of threat information.[55] However, subsequently, the nature of the terrorist threat to a wide range of facilities, including nuclear facilities, has been re-evaluated. These attacks showed that certain terrorist groups sought to cause mass fatalities and were prepared to sacrifice their own lives to achieve this goal.[56] A statement issued by the National Commission on Terrorist Attacks upon the United States indicates that according to assertions *'reportedly made by various September 11th conspirators and captured Al Qaeda members whilst under interrogation'* nuclear power plants in the United States were among the targets originally considered plans for the September 11th attacks. However the statement points out that staff have not had direct access to any of these individuals, and that all information comes from written reports, the credibility of which has had to be judged by the Commission.[57]

There are various factors which might affect the attractiveness of nuclear facilities, relative to other potential targets, to terrorists considering an attack. Analysts point out that an assault on a nuclear facility would not be guaranteed to cause a large release of radioactive material, and even if it did, there would not be large numbers of instant fatalities[58] - particularly since nuclear facilities are generally located away from major population centres. However, such an event could lead to significant numbers of long term cancers. Nuclear facilities may be more likely to be chosen as symbolic targets – an attack would serve to raise the profile of the terrorist group, and would be more likely to cause widespread social disruption than loss of life. The detonation of 'dirty bombs' in major population centres has been identified by many analysts as an easier and therefore potentially more likely mode of radiological attack. Nevertheless, public awareness of the terrorist threat to nuclear facilities has increased since 2001, as indicated by a survey of media coverage of Sellafield (see Annex 9).

4.4 Intelligence reporting within government

The government's assessment of the threat of any CBRN attack (including attacks on nuclear facilities) is provided by the Security Service, with support from Defence Intelligence staff. A recent report by the House of Commons Science and Technology Select Committee stated that there were a range of different risk assessments being carried out within government, and that it was *not clear who within government is responsible for determining what threats the UK should be responding to, and with what priorities.*[59] However, as the report pointed out, in June 2003

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[55] Note that the possibility of aircraft attack, although not widely discussed, was raised by some analysts as far back as 1975 following media reports that terrorists had threatened to fly a plane into a US reactor – see David Krieger, *Terrorists and Nuclear Technology,* Bulletin of the Atomic Scientists, Volume 31, 1975.

[56] It is beyond the scope of this report to comment on the capabilities of specific terrorist groups. Since September 11th the main focus has been on the threat from Islamic fundamentalist groups although there are certain parts of the world where other groups pose a significant threat – e.g. Chechen groups in the Former Soviet Union.

[57] National Commission on Terrorist Attacks Upon the United States, *Outline of the 9/11 plot*, *staff statement no. 16*, Also known as the 9/11 commission, this is an *'independent, bipartisan commission created by congressional legislation and the signature of President George W. Bush in late 2002, is chartered to prepare a full and complete account of the circumstances surrounding the September 11, 2001 terrorist attacks, including preparedness for and the immediate response to the attacks'.* See www.9-11commission.gov/

[58] G.Cameron, IAEA special session on combating Nuclear Terrorism, *Nuclear Terrorism: Reactors and Radiological Attacks after 11 September,* October 2001.

[59] House of Commons Science and Technology Committee, 8th report, Session 2002-2003, *The Scientific Response to Terrorism,* 20th October 2003.

the government set up a Joint Terrorism Analysis Centre (JTAC) in order to improve the quality of intelligence reporting.

JTAC co-ordinates threat assessments carried out by different organisations. It brings together bodies such as the Counter Terrorism Analysis Centre, the Secret Intelligence Service, the Security Service, Government Communications Headquarters and also Defence Intelligence Staff, the police and TRANSEC, the security division within the Department for Transport. OCNS is also a constituent member of JTAC. The MoD and OCNS use material from JTAC to determine what threats need to be considered in the protection of nuclear facilities.

The House of Commons Defence Select Committee has stated that security arrangements should not be based solely on intelligence information: *however valuable intelligence may be, experience shows that we cannot expect it to identify every threat or that every threat it does identify is real.*[60] OCNS states that security measures at nuclear sites are not determined on the basis of intelligence material alone, but by other relevant considerations such as the category of nuclear inventory.

4.5 Potential modes of attack

The Design Basis Threat

Official information on the potential scale and methods of terrorist attack at civilian nuclear facilities is contained within a document known as the Design Basis Threat (DBT) as recommended by the IAEA (Box 3-2). The contents of the DBT, drawn up by OCNS, are secret, although OCNS mentions two possibilities which are now included: the possibility that terrorists might *use vehicles loaded with explosives to crash through perimeter defences,* and *the threat that terrorists who were prepared to kill themselves or risk discovery might attempt to penetrate into* [certain sensitive areas inside sites] *to detonate explosives.*[61] The DBT makes clear which forms of possible attack the nuclear operating companies are expected to guard against and which remain the responsibility of the government, and whether, in the latter case, companies are still required to take mitigating or preventative measures.[62]

Different countries publish varying amounts of detail about the Design Basis Threat. There is more publicly available information on the US DBT than most other countries. Some of these are listed in Box 4-1, to illustrate the kinds of attack contemplated by authorities, although this provides no indication of the contents of the UK DBT.

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[60] Defence Select Committee, 6th report, session 2001-2002, *Defence and Security in the UK,* July 2002, Para 58.

[61] Office for Civil Nuclear Security, *The State of Security in the Civil Nuclear Industry*, April 2002- March 2003, (paragraph 35).

[62] Office for civil Nuclear Security, *The State of Security in the Civil Nuclear Industry*, April 2003-March 2004.

Box 4-1 The Design Basis Threat at US civilian facilities

There is some publicly available information about the US DBT for civilian nuclear sites. The US DBT is drawn up by the US Department of Energy in collaboration with other government departments. Prior to September 11th 2001 the scenarios considered included:

- Attacks by well trained and dedicated individuals, possibly with military training and skills.
- Attacks involving insider assistance.
- Attacks involving suitable weapons, up to and including hand held automatic weapons, equipped with silencers and having effective long-range accuracy.
- Attacks involving hand carried equipment, including incapacitating agents and explosives.
- Attacks involving a four wheel land drive vehicle to transport attackers and their hand held equipment to the proximity of vital areas.
- An attack involving a four wheel drive land vehicle bomb and insider assistance (this was added following the 1993 attack on the World Trade Centre).

More detailed information on the number of attacks, the type of weapons carried and the size of vehicle bomb is not publicly available. The US DBT was reviewed after September 11th 2001 and a new US DBT was introduced in May 2003. Full details are not available but a recent report by the US General Accounting Office (GAO) describes some changes:[63]

- The 2003 US DBT now *assumes* terrorists are well armed and equipped, trained in paramilitary and guerrilla warfare skills, willing to kill, risk death, commit suicide; capable of attacking without warning.
- Sites have to defend against a larger group of terrorists than in the 1999 US DBT.

The US Nuclear Energy Institute point out that *aircraft attacks and the use of sophisticated military weapons are not included in the Design Basis Threat.*[64] The GAO has criticised the US Department of Energy for taking over two years to revise the DBT and states that the threat identified in the new US DBT is less than that identified in the intelligence community's Postulated Threat, on which the US DBT has traditionally been based. The GAO also raises concerns that some sites will not meet the requirements of the new DBT by the deadline of the end of fiscal year 2006.

Other scenarios

There is a considerable amount of commentary in the public domain on possible modes of attack. Some examples of suggested scenarios include:

- **Ground based attacks:** In addition to the scenarios already discussed, analysts propose a number of additional scenarios - for example attacks from outside site security barriers using rockets or artillery.[65]
- **Attacks by air:** Suggested scenarios in published literature range from attack with a small aircraft loaded with explosives[66] or attack with a hijacked commercial aircraft through to the use of weapons from the air.[67] Note, however, that although considerable public attention was focussed on aircraft impact following September 11th, a number of commentators point out that other modes of attack might actually be more likely. For example, OCNS point out that *any further attacks by Al Qaeda, or any other extremist Islamic terrorist organisations, might be mounted from the ground. Terrorists would assume, correctly, that precautions against hijacking would now be much more stringent in the wake of those attacks.*
- **Maritime attacks:** analysts have also suggested that nuclear facilities, which often have coastal locations, might be vulnerable to attack by sea. Suggestions range from the possibility that terrorists might attempt to sabotage coolant systems of nuclear facilities, to more extreme

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[63] US General Accounting Office (GAO), *DOE Needs to Resolve Significant Issues Before it Fully Meets the New Design Basis Threat*, GAO-04-623, April 2004; *Several Issues could impede the Ability of DOE Office of Energy, Science and Environment to meet the May 2003 Design Basis Threat*, GAO-04-894T, June 2004. The US GAO is the audit, evaluation, and investigative arm of Congress.

[64] Personal communication from US Nuclear Energy Institute (NEI) to POST: The NEI is the policy organisation of the nuclear energy and technologies industry in the US and participates in both the national and global policymaking process. Further information can be found at www.nei.org.

[65] Institute for Resource and Security Studies, *Robust Storage of Spent Nuclear Fuel,* January 2003.

[66] G.E. Marsh and G.S. Stanford, *Terrorism and nuclear power: what are the risks?,* National Policy Analysis, US National Centre for Public Policy Research, November 2001, www.nationalcenter.org/NPA374.html .

[67] See footnote 65.

scenarios – e.g terrorists attempting to bring about an explosion involving a large liquefied petroleum (LPG) or natural gas (LNG) tankers passing the facility (see section 8.7).

Attack during transport

- **Causing an accident:** A number of analysts suggest terrorists might cause an accident by damaging transport infrastructure – e.g. destroying bridges to cause trucks and trains to fall.[68]
- **Attack with artillery or explosives:** Some analysts suggest terrorists might attack shipments either with anti-tank weapons, or with high explosives (e.g. a truck bomb or a truck carrying hydrocarbon fuel), or with a combination of both.[69]
- **Other**: Federal sponsored studies have recently been commissioned in the US to assess the impact of even more extreme scenarios, for example *a 20 passenger aircraft loaded with explosives crashing into [spent fuel] shipping containers.*[70]

The above examples are not based on official intelligence information and it is not possible to conclude whether any of these are currently realistic, or feasible for a terrorist group.

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[68] Nuclear Waste Project Office, State of Nevada, *Terrorism Considerations in the Transportation of spent fuel and radioactive waste,* Fact Sheet, 1997. www.state.nv.us/nucwaste/ .

[69] WISE-Paris, *The Transports in the French Plutonium Industry*, commissioned by Greenpeace, February 2003. WISE-Paris (www.wise-paris.org) is an NGO which reports on energy and environmental issues and has produced a number of reports on safety and security issues relating to Sellafield and Cap de la Hague (see refs. 66, 214,); WISE-Paris produced a study of plutonium transport in France in 2003 (section 10.6) for Greenpeace's 'Stop-Plutonium' campaign.

[70] United States General Accounting Office, *Spent Nuclear Fuel: Options to Further Enhance Security,* July 2003.

5 Vulnerability assessments part 2: physical robustness

5.1 Key points

- One of the most important principles on which modern nuclear plants operate is defence in depth, whereby several different systems perform the same function, so that the safety of the plant does not rely on any single feature. Defence in depth provides protection against terrorist acts as well as accidents.
- The range of accidents with which plants must be designed to cope, has been decided on the basis of their predicted *accidental* likelihood as well as the severity of their outcome. However, calculations of accidental likelihood are not relevant when considering terrorist acts. It is not possible to accurately assess the likelihood of a terrorist act.

5.2 Introduction

This chapter discusses the physical robustness of nuclear plants in relation to the safety assessment principles which were discussed briefly in Chapter 3. Section 5.3 describes engineering aspects of plant design. Section 5.4 discusses how safety analyses are carried out, and how decisions are made about the range of accident scenarios a plant must be designed to withstand, as this has also implications for the robustness of nuclear plants to deliberate attack by terrorists. Section 5.5 discusses the extent to which safety measures provide protection against terrorist acts.

5.3 Engineering principles for nuclear plants

Nuclear facilities in the UK are designed to meet the NII's Safety Assessment Principles (SAPs) for nuclear plants (Chapter 3). A fundamental aim of the SAPs is to ensure that the exposure of workers and the general public to ionising radiation is kept as low as reasonably practicable, as well as minimising the risk of accidents occurring, and to minimise the radiological consequences of any accident. This section provides a brief overview of the engineering principles employed to achieve these goals, as they also provide defence against terrorist attack. Design issues are then discussed in greater depth in subsequent chapters, for specific types of nuclear plant.

Containment and shielding

Containment structures act as barriers to release of radioactive material. The type of containment and the number of its levels depend on the facility. In general large sources of radioactive material (e.g. nuclear reactor cores, spent fuel storage facilities, storage facilities for high level radioactive waste) are housed in structures with thick steel reinforced concrete walls, designed to act as radiological shields (to prevent people from exposure to harmful levels of ionising radiation) as well as barriers. There has been a considerable amount of commentary on the robustness of such structures to external impacts (specifically aircraft crashes). However, predicting their response is not straightforward, as outlined in Box 5-1.

Box 5-1 Aircraft impact

There has been widespread debate over how nuclear installations would respond to aircraft impact. There are several mechanisms by which damage could occur:

- Damage to the entire building when energy is transferred from the aircraft to the building.
- Structural damage caused by individual hard components (e.g. the turbine shaft) acting as projectiles.
- Damage to plant safety systems and structures as a result of aviation fuel fires, in the event that aviation fuel penetrated the building.

The results of analyses of aircraft impact on nuclear installations, which are discussed in more detail in section 8.7, vary depending on factors including:

- The characteristics of the installation: the response of specific facilities is discussed in greater depth in subsequent chapters.
- The speed and angle of the aircraft – in general the faster the aircraft, the greater the impact. However it would be more difficult to target a facility with a fast moving aircraft. Also, the higher the approach angle,[71] the more difficult it would be to manoeuvre the aircraft.
- The size of the target relative to the size of the aircraft: the smaller the facility, the harder it would be to target accurately. For example a PWR has a height and diameter of around 60 metres, comparable to the wingspan of a large passenger plane.
- The type of aircraft – for example, response to a large fuel laden passenger jet would be different to a military aircraft, on which many earlier studies were carried out.

Considerable uncertainty arises due to difficulties in estimating the penetrating powers of projectiles, due to limited availability of experimental data,[72] and problems applying standard formulae for penetration of concrete by regular projectiles, to the more complex scenario of aircraft impact. Early studies on US facilities by the US Nuclear Regulatory Commission, considered that a large aircraft had a 1 in 2 chance of penetrating a spent fuel cooling pond. However, the NRC now states that additional research indicates that '*prior assumptions regarding the probability of engine turbine shaft penetration are conservative by orders of magnitude and thus penetration is much less likely than previously assumed*'.[73] Some analysts take a more pessimistic approach, arguing that '*it is quite reasonable to assume that the building containment would be breached* [during an aircraft crash]*…because of the absence of any extraordinary civil engineering features visibly incorporated into the building design and arguing that even relatively small penetrations will permit the inflow of aviation fuel which could cause further structural damage*'.[74]

Defence in depth

One of the most important principles on which modern nuclear plants are based is **defence in depth**, whereby several different systems perform the same function, so that the safety of the plant does not rely on any single feature. The principle of defence in depth also applies to security, and involves having a series of 'zones' that have to be penetrated in succession, so introducing time delays and additional challenges – for example successive security turnstiles requiring access control passes. Defence in depth involves three key concepts: redundancy, diversity, and segregation.

- **Redundancy** - for example, in the case of a nuclear reactor, there are multiple systems to shut the reactor down, multiple power supplies or multiple barriers to contain any release of radioactive material.
- **Diversity** - ensuring that systems performing the same function are not identically designed, so that manufacturing errors, for example, do not affect all systems at once.

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[71] The inclination of the aircraft to the horizontal.

[72] Some experimental data are available from studies of the experimental crash of a Phantom jet into a reinforced concrete wall conducted by Sandia National Laboratories in 1988. The jet was crashed perpendicular to the wall at a velocity of 215 m/s (774 km/h). The wall was only slightly damaged and the maximum penetration depth was 60 mm; a report by the Swiss nuclear regulator (see reference 147) attributes this to *the fact that the reinforced concrete wall was mounted atop an air-bearing platform.*

[73] http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/reducing-hazards-spent-fuel.html

[74] Large and Associates, *The implications of September the 11th for the Nuclear Industry,* February 2003. http://www.oxfordresearchgroup.org.uk/publications/CDRs/LargeandSchneider.pdf. Dr John Large is a consulting engineer who has published widely on nuclear safety and security issues both in the UK and overseas, recent publications include *Potential Radiological Impact and Consequences arising from Incidents involving a Consignment of Plutonium from COGEMA/La Hague to Marcoule/Cadarache*; Commissioned by Greenpeace, March 2004.

- **Segregation** - can reduce the chance of a common hazard (e.g. flood or fire) damaging more than one system. It can be achieved either by means of barriers or by placing systems in separate physical locations.

All plants are designed according to the above principles, but in general, the more modern the plant, the higher the level of redundancy, diversity and segregation.

Safety features

The SAPs stipulate that safety should be maintained through the use of two types of safety systems, defined as follows:

- **Inherent safety** - where specific hazards are eliminated either through a design concept or a choice of material. An example of such a feature in, some modern nuclear reactors is the 'negative power coefficient' where an increase in power output leads to a decrease in the rate of the nuclear chain reaction, limiting the risk of a runaway nuclear reaction (see Box 2-1).
- **Passive safety** - where the safety of the system does not rely on operator control or on mechanical systems. For example, liquid high level radioactive waste storage is not a passively safe activity because it requires constant operator supervision and relies on equipment such as pumps and generators to maintain safe conditions. Solid high level radioactive waste is more passively safe because it does not have these requirements.

If faults do occur, the SAPs also stipulate that systems should be designed to fail '*in a safe manner*', i.e. in such a way that the situation can be kept under control.

5.4 Classification of accidents at nuclear plants

The Safety Assessment Principles state that all reasonably practicable steps must be taken to prevent accidents at nuclear plants, and to minimise the radiological consequences of an accident. Thus, nuclear plants are designed to cope with a wide range of potential accidents, known as **design basis accidents**. The predicted accidental frequency of an accident largely determines what accidents fall into this category (see below). Thus, plants are not designed to cope with more unlikely accidents which fall outside the design basis (although they may have some capacity to mitigate the consequences of such events), as this is not considered 'reasonably practicable'. Such accidents are known as **beyond design basis accidents.**

As part of the plant safety case an operator must carry out a safety analysis considering both normal conditions and accident conditions, verifying that the performance of the plant complies with the SAPs. There are three parts to the accident analysis, discussed below.

Design basis analysis

This analysis must show that for design basis accidents, resulting radiation doses lie below specified limits. All 'initiating faults' predicted to occur with an accidental frequency of above 1 in 100,000 p.a. (per annum) must be included in the analysis (with some exceptions).[75] The safety analysis must then consider all accident sequences arising from each initiating fault. It must demonstrate that there is no release of radioactivity except in the most severe cases, in which case no member of the public will receive a radiation dose over 100 mSv.[76] It must also demonstrate that at least one physical barrier to the escape of radioactivity remains intact.

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[75] An 'initiating fault' could be anything from a relatively small incident such as minor component failures to potentially more serious incidents such as a fires within the plant.

[76] i.e. 10-100 times the natural background radiation dose of 1-10 mSv per annum.

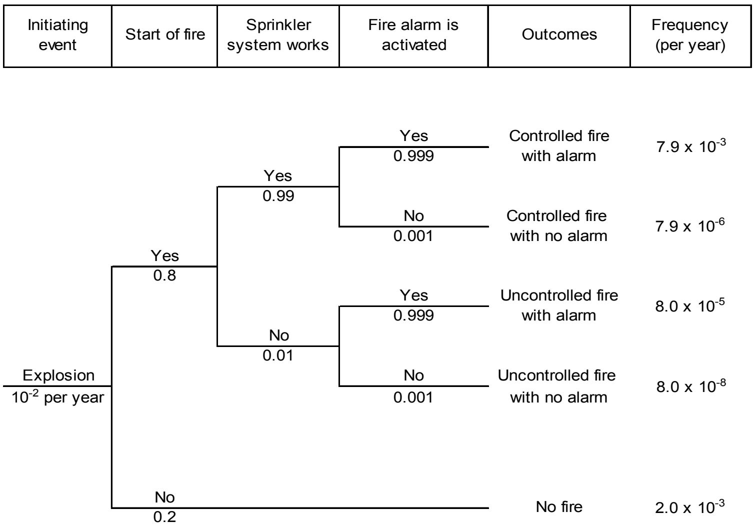
Severe accident analysis

By definition, plants do not have to be designed to cope with ‘beyond design basis’ accidents – so there is no upper limit on the radiation doses people might receive in such scenarios. Nevertheless the safety analysis must demonstrate that the radiological consequences of such accidents are understood and that accident management strategies are in place.

Probabilistic Safety Analysis (PSA)

This must be carried out to give a quantitative indication of the risk posed by the plant. The PSA predicts a frequency of occurrence for all possible accident sequences arising from each initiating fault. These are evaluated by means of ‘event trees’ or ‘fault trees’ (see Figure 5-1) where the probability at each branch of the tree is known.[77] The total frequency of occurrence of accidents giving rise to a specified outcome must then be shown to fall below specified limits.[78] These limits are adjusted according to the severity of the consequences of an accident – the more severe these are, the more stringent the limits.

Figure 5-1 Example of an Event Tree Analysis



Source: International Electrotechnical Commission (IEC)[79]

5.5 Safety provisions and the terrorist threat

As seen in this chapter, the Safety Assessment Principles for nuclear plants (section 3.4) are not specifically designed to address security threats, such as terrorist attacks on nuclear facilities. However, many of the measures taken to enhance safety also provide defence against terrorist attack. For example, because of defence in depth, terrorists would have to damage several systems or components in order to bring about a significant release of radioactive material – damage to any individual system should not be enough to cause a release. Where physical segregation of systems is employed, terrorists would have to simultaneously attack more than one area of a plant to bring about a release. Multiple containment structures intended to act as

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[77] Based on statistical data, for example on component reliability or operator performance, or on best estimates, where data is not available.

[78] This outcome can be expressed in terms of both total releases of radioactive material and radiation doses for workers and the public.

[79] The author thanks the IEC for permission to reproduce information from its International Standard IEC 60300-3-9. Further information on the IEC is available from www.iec.ch. All such extracts are the copyright of IEC, Geneva, Switzerland. All rights reserved. IEC has no responsibility for the placement and context in which the extract is reproduced by the author, nor is the IEC responsible in any way for the content or accuracy therein.

barriers to *accidental* release of radioactive material will also fulfil the same function in the event of a terrorist attack. However, there are potential conflicts between safety and security requirements. For example, in the interests of security it might be desirable to minimise the number of access doors, but additional emergency exits are required under safety and fire regulations.

Frequency of occurrence

As seen in section 5.4, the range of accidents with which plants must be designed to cope, has been decided on the basis of their predicted *accidental* frequency of occurrence as well as the severity of their outcomes. However, Greenpeace point out that accidental frequencies are not applicable to deliberate terrorist acts.[80] It is not possible to make similar quantitative predictions on the likelihood of occurrence of a terrorist act, as one cannot quantify the intentions of a terrorist group. Some commentators point out that once the assumption is made that an attack has been initiated, the probability of its success is much larger than the equivalent accidental frequency.[81] However, without information on the likelihood and nature of the attack itself, such figures are hard to place in context.

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[80] Greenpeace, *The Potential for Terrorist Strikes on Nuclear Installations,* 2001.

[81] Large and Associates, *The implications of September the 11th for the Nuclear Industry,* February 2003.

6 Vulnerability assessments part 3: security arrangements

6.1 Key points

- It is difficult to comment on the robustness of security regimes at UK nuclear facilities given that there is very little information in the public domain. Although the UK carries out practical security exercises at nuclear facilities, there is little information about what lessons are learned from these exercises or how often they take place.
- Greenpeace claims that security breaches by protesters at nuclear sites demonstrate deficiencies in security arrangements. However, the Office for Civil Nuclear Security argues that intrusions by protest groups are different in character and scale to attacks likely to be attempted by armed terrorists.
- Some UK civil nuclear sites, including Sellafield and Dounreay, are protected by on-site armed police, and OCNS may deploy armed or unarmed officers at any civil nuclear site if it believes that circumstances justify this.
- It is not the responsibility of civil nuclear site operators to prevent non ground-based attacks such as aircraft impact. This is seen as the government's responsibility although site operators might be expected to take certain mitigating or precautionary measures.
- A range of other facilities, such as utilities, chemical or petrochemical facilities, are also vulnerable to terrorist attack. There are no comparative risk assessments of these different facilities in the public domain.

6.2 Introduction

This chapter focuses on specific aspects of security regimes at UK civilian nuclear sites. Section 6.3 describes the use of guards, outlining the role of the UK Atomic Energy Authority Constabulary (AEAC), and discusses policy on the use of force and the handling of protests at nuclear sites. Section 6.4 outlines changes made to security arrangements at nuclear sites in the past three years, and discusses the impact of the September 11th 2001 events on the type of information that can be placed in the public domain. Section 6.5 explains how sites rely on external assistance from the UK's existing national defence framework for protection against non ground-based terrorist attacks (e.g. aircraft impact). Section 6.6 briefly discusses security at civil nuclear sites in France.

6.3 Guarding of nuclear sites

As explained in Chapter 5, there are four key ways of protecting facilities against hostile acts - through hardware (i.e. alarms, security gates, etc.); people (e.g. guards); through procedures and systems, or through the design of the facility itself. Arrangements for the provision of guards at civilian sites vary depending on the nature of the site. Armed civilian guards are not permitted in the UK. Only members of the armed services and the police are permitted to use firearms. OCNS decides on the minimum time within which an armed response capability must be in place at each civil nuclear site, and arrangements are made on this basis:[82]

- Certain sites are protected by armed police from the UKAEA constabulary, the AEAC (see Box 6-1). The AEAC's role at these sites is to provide an immediate armed response pending the arrival of the local response force (i.e. police). It maintains a police presence at all perimeter gates and certain designated sensitive buildings inside sites. There are also officers patrolling

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[82] Under UK law, a civilian response capability can only be provided by a properly constituted and authorised police force.

the periphery of these sites. The AEAC also provide armed escorts for civilian transport of Special Nuclear Material.[83]

- Civilian nuclear sites which are not protected by on-site AEAC armed police are protected by unarmed civilian guards whose role is to not to prevent attacks but to detect and deter any attack until the police response can arrive. Since the jurisdiction of the UKAEA has recently been extended, arrangements have been made to provide mobile cover while consideration is given to stationing armed police at these sites.[84] The length of time required for a response force to arrive in the event of an attack would be crucial in determining whether the attack could be prevented.

In practice the security of a site depends on the reliability of all personnel. Therefore, vetting arrangements are in place to ensure their trustworthiness (Box 3-3) . OCNS has stated that even the local population plays a role and that '*workers and their families and the local police are encouraged to report strangers behaving suspiciously.*'[85]

Box 6-1 The United Kingdom Atomic Energy Constabulary (AEAC)[86]

The AEAC was set up as part of the UKAEA by the Atomic Energy Authority Act 1954, with a statutory remit to protect nuclear material on behalf of the government both on UKAEA sites and in transit. Its remit has broadened and AEAC now operates at Dounreay, Harwell and Winfrith (UKAEA), Sellafield, Chapelcross and Springfields (BNFL) and Capenhurst (URENCO). There are around 650 police in total, trained at a nationally accredited training centre, including advanced training in the use of firearms and associated tactical response. Armed UKAEAC officers can be deployed at any civil nuclear site in the UK. Deployment details are determined by OCNS and are classified. The duties of the constabulary include:

- Controlling access to establishments and segregated areas within them.
- Ensuring physical safety of buildings by carrying out foot, mobile and dog patrols.
- Providing armed escorts for the movement of UKAEA and BNFL special nuclear materials (SNM).
- Manning communication centres and control rooms.
- Ensuring an effective response in the event of a terrorist attack. Contingency plans have been made in conjunction with the local (i.e. Home and Scottish Executive) police forces.
- Providing general policing at sites including traffic control and investigating crime.

AEAC has an annual budget of around £30 million which is met by the operators in proportion to the support they receive. Plans to make the AEAC an independent statutory force are outlined in the Energy Bill currently before Parliament.

When to use force

Even when guards are armed, the use of force is not a straightforward issue. The decision to use force might rest with the individual guard, for example if there were insufficient time for a response strategy to be planned in advance. Individual guards might therefore have to make very rapid judgements on the level of threat faced (for example distinguishing between a protester and a genuine attacker). OCNS explains that AEAC police are well aware that *they may be called upon at any time, without warning, to use their weapons* and that in such an eventuality *their actions would be closely scrutinised.* The 2002 Defence Committee report on *Defence and Security in the UK* explains that *the use of lethal force in English law is justified when used in self defence, defence of others, or in the prevention of crime where there is an imminent threat to life and the force used is reasonable (necessary and proportionate) having regard to all the circumstances.* Policies on armed response vary in different countries. For example in the United States, all civilian nuclear power plants are protected by armed guards on-site (Box 6-2).

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[83] Her Majesty's Inspectorate of Constabulary, 2002/2003 Inspection of the United Kingdom Atomic Energy Constabulary, 2003.

[84] Office for Civil Nuclear Security, *The State of Security in the Civil Nuclear Industry*, April 2003- March 2004.

[85] Office for Civil Nuclear Security, *The State of Security in the Civil Nuclear Industry*, October 2000 - March 2002, para. 59; para. 6.

[86] http://www.ukaea.org.uk/ukaeac/index.htm

Box 6-2 Armed response at nuclear facilities in the US

In the United States, all civilian nuclear power plants are protected by armed guards on-site. Prior to September 11th 2001, the USA had approximately 5,000 armed guards at their 63 nuclear facilities. This number has been now increased to 7,000. A recent report by the US General Accounting Office criticised security at US commercial nuclear power plants. The report pointed out that although guards at these sites were armed, *federal law generally prohibits guards at these plants from using automatic weapons, although terrorists were likely to have them* and that *state laws vary regarding the permissible use of force and the authority to arrest and detain intruders, and guards are unsure about the extent of their authorities and may hesitate or fail if the plant is attacked.*[87]

Protests at nuclear sites

There have been several incidents where protest groups have attempted to gain access to nuclear sites, for example Greenpeace's intrusions into the Sizewell B plant on 14th October 2002, and 13th January 2003. On the second occasion a group of over 30 protesters succeeded in scaling the perimeter fence surrounding the site. On both occasions the protesters gained access to the reactor building. They also managed to scale the dome surrounding the reactor building.

Following this intrusion, OCNS reported that action has been taken to protect the station perimeter, including the installation of more razor wire around certain parts of the fence, but state that *no practicable, cost-effective combination of perimeter fencing and other obstacles can prevent large numbers of demonstrators from breaching outer barriers* and that *the purpose of perimeter barriers is to delay and detect intrusions taking place and afford time for contingency arrangements to be achieved*. Greenpeace claims that security breaches by protesters at nuclear sites demonstrate deficiencies in security arrangements.[88] However, OCNS claims that intrusions by protest groups are different in character and scale from attacks likely to be attempted by armed terrorists, who would not operate in such large numbers and would try to get as close as possible to inner areas before being detected. Nevertheless, the protesters managed to gain access to the Inner Secure Zone of the reactor site via a fire door which was inadvertently left unlocked,[89] which OCNS confirm *should not have been possible*. OCNS point out that by increasing the number of inspectors it has been possible to '*review the position quickly at other sites as well as Sizewell B*'.[90]

In the UK, there is no specific legislation relating to intrusions on civil nuclear sites (as there is for airports and the Channel Tunnel). Civil operators rely on the civil law of trespass to deter unauthorised intrusions.[91]

6.4 Changes made since September 11th 2001

After September 11th 2001, the nuclear operators and regulators undertook an extensive review of security arrangements at nuclear sites. Full details of measures taken cannot be made public. Some of those taken at civilian facilities are discussed below. Practical measures include:

- Increased searches of personnel, vehicles and additional patrols.
- For all sites, tours for the general public have stopped and will not be permitted for the

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[87] US General Accounting Office, *Oversight of Security at Commercial Nuclear Power Plants Needs to be Strengthened,* September 2003 GAO-03-752. Note that the US nuclear regulator, the Nuclear Regulatory Commission, criticised the GAO report, arguing that it *misrepresented the current high level of security at* [these nuclear] *facilities.*

[88] Greenpeace, *The Potential for Terrorist Strikes on Nuclear Installations,* 2001.

[89] British Energy points out that protesters gained access to 'ancillary' areas of the reactor building only.

[90] Office for Civil Nuclear Security, *The State of Security in the Civil Nuclear Industry*, April 2002- March 2003,

[91] Note that the civil rights group Liberty states that peaceful protesters at RAF Fairford in Gloucestershire in March 2003 were searched and arrested under the Anti Terrorism Act 2001 and are challenging the use of search powers against legitimate protesters. See Liberty, *The right to protest and section 44,* 2003. See http://www.liberty-human-rights.org.uk/issues/right-to-protest.shtml .

foreseeable future. More limited visits by e.g. local school groups have continued, subject to tighter security restrictions.
- Restriction of information in the public domain (see next page).
- Installation of chicanes at entry points to nuclear sites to prevent unauthorised vehicle access. Some chicanes have now been replaced with permanent purpose-designed barriers, new traffic management schemes to strengthen sites against vehicular attacks, re-surveying perimeter fences and provision of additional anti-crash features.
- Examination of safety and security arrangements at 'Vital Areas' - the aim is to understand the effectiveness of existing safety and security features and the extent to which they might prevent or mitigate a serious radioactive release following a sabotage attack. This programme began at Sellafield and has also been extended to other nuclear sites.

Note that some changes are made reactively, in response to specific breaches in security. For example, in 2002 a *News of the World j*ournalist with fake references succeeded in gaining access to the inner area of Dungeness B nuclear power station in Kent, with a camera.[92] British Energy strengthened its searching and escorting arrangements after this event.

Legislation

Under the Anti Terrorism, Crime and Security Act 2001, the following changes were made:
- It was made a criminal offence to disclose information intentionally or recklessly which might compromise the security of a nuclear site or nuclear material.
- New powers were granted to the UKAEA constabulary, including the right to exercise full police powers within 5 km of nuclear sites.
- The Act enabled legislation to be introduced to modernise civilian nuclear security arrangements (Box 3-3).

Information in the public domain

After September 11th 2001, a considerable amount of information on nuclear activities from official sources was withdrawn from the public domain as it was regarded as potentially being of use to terrorists. For example, in the UK, maps showing the layout of nuclear sites are no longer available. Under the Anti-terrorism, Crime and Security Act 2001, it became a criminal offence for anyone to make an intentional or reckless disclosure of information that might affect the security of nuclear premises or nuclear material. Under the Nuclear Industry Security Regulations 2003, the civil nuclear operating companies are also required to keep such information secure. However, a considerable amount of information can be found through other public sources.

There is an inevitable conflict between the need to protect sensitive information, and the need to keep the public informed. In its report on *Defence and Security in the UK* in July 2002, the House of Commons Defence Select Committee suggested that '*information should only be withheld from the public only where its publication would give rise to a specific and identifiable risk*'. The lack of public information on security issues makes informed public debate difficult, although there are some steps being taken to facilitate dialogue – for example as part of BNFL's National Stakeholder Dialogue (Box 6-3).

All countries have restricted information placed in the public domain since September 11th 2001, though there is widespread variation in the amount of information available. In the UK, there was a move towards making more information available to the public on nuclear activities before 2001. The Nuclear Installations Inspectorate published a number of reports on safety - such as

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[92] News of the World, *Nuke Nightmare,* 8th September 2002.

Box 6-3 BNFL National Stakeholder Dialogue

BNFL is engaged in dialogue on security and safeguards issues with official bodies (including OCNS, the NII) as well as representatives from NGOs. This is part of the BNFL National Stakeholder Dialogue, which aims to discuss long term solutions to environmental issues. Previously, the Plutonium Working Group concentrated on plutonium storage, MOX and plutonium transport, and associated security and safeguards considerations. One of the aims of the new Security Working Group is to probe where the balance should lie between informing the public and keeping sensitive information out of the hands of terrorists. It is expected to publish its final report in September 2004. Other dialogues have included working groups on waste management, environmental discharges and spent fuel management options. In the past, the outcome of dialogues has influenced policy decisions. For example, as a result of the Plutonium Working Group report, BNFL agreed to devote more resources to technology options for disposal of plutonium that had no further nuclear use.

The storage of liquid high level waste at Sellafield in 1995 and 2001, after a public meeting. These reports discuss the design of the liquid high level waste tanks at Sellafield and the volume of waste they contain, as well as safety systems and procedures – although some analysts point out that more detail would be needed to assess the vulnerability of the facilities to terrorist attack.[93] In comparison, in France, the nuclear regulators have not made similar detail available about any French nuclear plants. These NII reports are still publicly available, although it is unlikely that such public meetings would take place today, or that further reports with this level of detail would be published.

A considerable amount of security related information is made available by US authorities. For example the General Accounting Office (GAO) and the Nuclear Regulatory Commission (NRC) regularly publish reports relating to nuclear activities. A recent report by the GAO discusses options to enhance security of spent fuel, and includes diagrams of spent fuel flasks as well as of the trucks or rail wagons that would be used to transport them. Individual states (e.g. the State of Nevada)[94] have discussed the kinds of artillery that might be available to terrorists and their potential impact on spent fuel flasks.[95] In the UK, official reports do not cover these issues in a similar level of detail, although OCNS has published an annual report on *The State of Security in the Civil Nuclear Industry* since 2002, as a means of informing the public about security issues.

6.5 External assistance

The UK DBT does not require site operators to have arrangements in place to prevent some forms of attack such as large aircraft impact. It is recognised as the government's responsibility to deal with such threats via the UK's existing defence framework, although operators might be expected to take certain mitigating or precautionary measures, the details of which are classified. Air defence and sea defence are discussed briefly in this section.

Defence against an attack by air

There are very few details in the public domain of specific arrangements to protect nuclear sites against attack from the air. OCNS states that changes relating to air defence around civilian nuclear facilities include *strengthened warning procedures and interdiction by RAF interceptor aircraft*[96] (see Box 6-4). It also points out that the UK response to September 11th 2001, differs from the initial response in France, which was to deploy anti-aircraft missiles outside the French

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[93] Institute of Resource and Security Studies (IRSS), *High Level Liquid Radioactive Waste at Sellafield: Risks, Alternative Options and Lessons for Policy,* 1998 ; IRSS, *High Level Liquid Radioactive Waste at Sellafield: Risks, an Updated Review,* 2000.

[94] See for example http://www.state.nv.us/nucwaste/yucca/terrfact.htm .

[95] These studies are not directly applicable to the UK because the practices involving spent fuel differ.

[96] Office for Civil Nuclear Security, *The State of Security in the Civil Nuclear Industry*, April 2000- March 2002, para 41.

reprocessing plant at Cap de la Hague (although these were removed within three weeks).[97] The UK has been criticised for not taking similar action.[98] However, there is controversy over whether anti-aircraft missiles are a reliable form of defence at such facilities. For example, the House of Commons Defence Committee does not believe that ground-based missiles can be an effective deterrent against air attack, or that their use against civilian aircraft cannot be justified.[99]

Major nuclear installations in the UK now have a restricted area of two nautical mile radius.[100] There have been several questions asked in Parliament in 2004, relating to alleged breaches of these zones.[101] On 6th May 2004, the MoD presented Parliament with a list of 'near miss' incidents around nuclear sites, revealing that there had been 59 alleged breaches of aircraft exclusion zones since 2000, of which four are confirmed, and one is still under investigation.

Defence of UK nuclear facilities against attack by air is provided by the existing national arrangements involving Quick Reaction Alert aircraft or QRA (see Box 6-4). However, the Defence Select Committee's report on *Defence and Security in the UK* questioned whether there would be time for a QRA to respond to a rogue civilian aircraft, and also highlighted that there were many obstacles in the way of taking a decision to shoot down an aircraft, even as a last resort.

Discussions of the feasibility of intercepting hijacked aircraft have also occurred in the context of aircraft attack at Sellafield (see Chapter 12).

Box 6-4 UK Air Defence [102]

UK air defence is undertaken as part of the NATO Integrated Air Defence System (NATINADS), which was designed to counter the soviet threat. UK air space is controlled by a Combined Air Operation Centre (CAOC) at RAF High Wycombe. Activities include surveillance of airspace, detection of unusual activity and active policing and response through use of interceptor aircraft known as Quick Response Aircraft (QRA) .

The House of Commons Defence Committee's report into *Defence and Security in the UK* made the following points about UK air defence:

- Time available to respond - it doubted whether there would be sufficient time for QRA to respond to any perceived threat. It pointed out that when the 2001 attacks in the US took place, interceptor aircraft were still over 100 miles away when the crashes occurred. The Committee noted that *QRA aircraft response times depend on geographical location*. The RAF has repositioned its aircraft after September 2001.
- Establishing 'hostile intent' [103] - the Committee pointed out that '*establishing hostile intent would not be straightforward and that whether to shoot [an aircraft] down would be a terrible decision to take. And there would be very little time in which to take it.*'
- Authority to take decisions - in the USA, the arrangements are that such a decision would be taken by the President, but if time did not permit, authority could be given by a Major-General. However MoD officials told the committee that such procedures are not followed in the UK. The committee recommended that only Ministers should have the authority to take such a decision.

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[97] However, anti-aircraft missiles are designed to be mobile and rapidly deployed.

[98] Greenpeace, *The Potential for Terrorist Strikes on Nuclear Installations,* 2001.

[99] Defence Select Committee, 6th report, session 2001-2002, *Defence and Security in the UK*, July 2002.

[100] Note however that OCNS state that no-fly zones were not extended to increase defence against terrorist attacks, but are intended as safety features designed to reduce possibly dangerous low overflights by, e.g. amateur pilots.

[101] HC Deb, 27th April 2004, 874W ; HC Deb, 6th May 2004, 1714W.

[102] Defence Select Committee, 6th report, session 2001-2002, *Defence and Security in the UK*, July 2002.

[103] 'Hostile intent' is defined as *demonstration of an intention imminently to use the aircraft as a weapon and in a manner that will lead to loss of life.*

Attack by sea

As with air defence, nuclear sites rely on the UK's existing defence framework for protection against attack by sea – i.e. the Royal Navy. However, the House of Commons Defence Committee report pointed out that *no military naval patrol is maintained specifically for counter-terrorism deterrence … although a frigate or a destroyer….may be expected to have the capabilities needed to undertake counter terrorist duties* and that *the inherent flexibility of warships enables them to deploy, at short notice, the support of maritime interdiction.*

6.6 Security at civil nuclear sites in France

It is beyond the scope of this report to provide a comprehensive comparison of security arrangements at nuclear sites in different countries. However, an overview of what is known about security arrangements at French nuclear sites is provided in the box below, because of the proximity to the UK of several nuclear sites along the northern French coast, and the size and nature of the radioactive inventory held at the reprocessing plant at Cap de la Hague.

6.7 Security of civilian nuclear activities relative to other industries

Several other activities – for example utilities, or chemical and petrochemical facilities – are also vulnerable to terrorist attack and have less stringent security requirements than at nuclear sites. Stakeholders submitting comments to the UKAEA quinquennial review noted that *other hazardous industries are not required to maintain a police presence at operational sites even though, arguably, the potential hazards from such sites are similar to those posed by special nuclear materials*[104]. Also, according to the US Nuclear Energy Institute, the US Department of Health are *realising that chemical and petrochemical facilities pose significantly greater risks to the populations and are far less able to thwart an attack.*[105]

To perform a qualitative assessment of the relative hazards posed by nuclear activities compared with other hazardous activities, one would need to take into account many factors including:

- Differences in security arrangements;
- Differences in the physical robustness of the facilities involved;
- Differing environmental and health consequences of any release of hazardous material.

There is no such comparison in the public domain although there may be classified analyses.

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[104] http://www.dti.gov.uk/energy/nuclear/environment/ukaea_qqr/report.shtml

[105] Personal communication from Nuclear Energy Institute to POST, August 2003.

Box 6-5 Security at civil nuclear sites in France

Regulatory framework

Safety and security regulations at French nuclear plants are the responsibility of a single regulator.[106] As in the UK, operators must produce a safety case which is assessed by the regulator to obtain a licence. In addition, operators must demonstrate how malevolent actions specified in the Design Basis Threat (both theft and sabotage) are taken into account in the design and operation of the facility. This has been a regulatory requirement since 1958.[107] Also, security exercises are carried out on a regular basis.

Guarding

French nuclear power plants do not have on-site armed response, but are protected on-site by unarmed civilian guards. Arrangements are in place for intervention by an armed response force - either from the civilian national police force (Police Nationale) or from the GIGN,[108] a military elite corps which forms part of the Gendarmerie Nationale. Some sites, such as COGEMA's plant at Cap de la Hague, have an on-site armed response capability.[109]

Changes made since September 11th 2001

Changes made mainly fall into the following categories:

- Review of the Design Basis Threat - the DBT was upgraded, although threats such as truck bomb attacks and commando style attacks were already taken into account. As with the UK, protecting sites against non ground-based attacks such as aircraft impact is primarily the responsibility of the state, rather than the operator. Revised threat assessments were also carried out but the results are largely classified.
- Physical protection (surveillance) - *Operation Vigipirate,* the government's counter terrorist operation*,* was implemented. Under this plan several hundred military personnel are deployed to reinforce the Police and Gendarmerie, to patrol and guard sensitive sites. This system was first introduced in 1986 after a series of terrorist attacks in France and was upgraded in 2001, when several new levels of security alert were defined.
- Physical protection (access) - measures included extension of no-fly zones, limiting vehicular access to sites, increased checks of parcels and packages being delivered to sites, extension of security vetting of personnel, removal of information on public web sites and stopping of public tours of all sites.
- Physical protection (other): measures were taken to strengthen on-site and off-site response – for example, arrangements were made to accommodate an armed response at nuclear power plants in the event of an attack. Immediately after the attacks, anti-aircraft missiles were stationed outside the Cap de la Hague plant.
- Inspections: unannounced inspections were carried out at 26 sites, and the frequency of security inspections at all sites has been increased.
- Regulatory changes: plans are underway to introduce new regulations which clarify the allocation of responsibilities for physical protection of nuclear sites.

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[106] Direction Générale de la Sureté Nucléaire et de la Radioprotection, supported by the Institut de Radioprotection et de Sûreté Nucléaire, an independent body with expertise in technical and security issues.

[107] Ordonnance No. 58-1371 '*tendant a renforcer la protection des installations d'importance vitale*', 29 December 1958; Ordonnance No. 59-147 '*portant organisation generale de la defense*', 7th January 1959.

[108] Groupe d'Intervention de la Gendarmerie Nationale.

[109] COGEMA is a company that provides services to the civil nuclear industry.

7 Vulnerability part 4: evaluating the consequences

7.1 Key points

- The ionising radiation emitted by radioactive materials can damage living tissue, mainly through damage to cell DNA. Exposure to ionising radiation has been associated with a range of health effects, from acute radiation sickness to increased risk of long term cancer.
- There are significant uncertainties involved in predicting the environmental and health consequences of radiological releases from nuclear facilities.
- This is largely due to incomplete knowledge of the 'source term' (the size and nature of the release), uncertainties in predicting weather conditions, and assumptions made about emergency planning arrangements .
- Analyses carried out by UK nuclear operators to investigate the consequence of accidents at nuclear plants could give an indication of the potential consequences of terrorist attacks. However with the exception of Sizewell B these analyses are largely not publicly available.
- The consequences of the release also depend on the properties of the radionuclide released, its movement through the environment and its uptake by the human body.
- In the event of a release, decisions on the implementation of countermeasures to protect the public would not be solely based on the need to limit the public's exposure to ionising radiation, but take into account wider issues such as economic cost and social disruption.

7.2 Introduction

This chapter describes the factors affecting the consequences of releases of radioactive material from nuclear facilities. It begins with a discussion of the health hazards associated with radioactive materials in section 7.3. Section 7.4 then discusses how radioactive material moves within the environment, the different ways in which people can be exposed to ionising radiation and the properties and health effects of several radionuclides. Section 7.5 describes how decisions are made on how to protect the public in the event of a release (this is examined in more depth in Chapter 11). Section 7.6 discusses how modelling is used to predict the consequences of releases.

7.3 Health hazards associated with radioactive materials

There are two main health hazards associated with radioactive materials:

- The ionising radiation emitted by radioactive materials can damage living tissue. Exposure to excess ionising radiation has been associated with a range of health effects, from acute radiation sickness to an increased risk of long term cancer.
- Radioactive materials can be chemically toxic as well as being radioactive. Examples include uranium and plutonium, which are heavy metals. In the case of uranium, which is only weakly radioactive, the chemically toxicity of uranium is the greater health risk.

Exposure to ionising radiation is the main hazard focussed on in this report, as chemical toxicity is not uniquely associated with radioactive materials.

The biological effects of ionising radiation

All living things are exposed to background levels of ionising radiation, due to naturally occurring radionuclides in the environment as well as cosmic rays. However, man-made activities can

Box 7-1 Measuring radiation effects on the human body

The energy imparted by ionising radiation from radioactive material can cause damage to the cells of the body, mainly through damage to cell DNA. Cells may be killed as a result of this damage. If they survive, they may have incorrectly repaired the damage to their DNA and therefore they may carry mutations. Certain types of mutations leave the cell at greater risk of becoming cancerous in the future.[110]

The extent of the biological damage caused by ionising radiation depends on a number of factors:

- The energy deposited per unit volume (the 'energy density') - the higher the energy density, the more damage can be done to tissue. The energy density depends on the type of radiation - for example alpha particles (see Annex 1) deposit their energy over shorter distances than beta or gamma radiation, so once they are inside the body they are more damaging than beta or gamma.
- The susceptibility of the organ receiving the radiation.

Dose quantities may be measured in several ways, which take different factors into account:

- The **absorbed dose** measures the amount of energy deposited in a tissue and is measured in grays (Gy).
- The **equivalent dose** reflects that different types of radiation cause different levels of damage. It is calculated by multiplying the absorbed dose by a weighting factor for each type of radiation and is measured in sieverts (Sv).
- The **effective dose** is the most widely used measure of the risk from exposure. It reflects both the damage caused by different types of radiation and the variable susceptibility of different organs in the body. It is calculated by multiplying the equivalent dose by a weighting factor for each organ and is also measured in sieverts (Sv).

Exposure to radiation is normally quoted in millisieverts (mSv) – one mSv is the equivalent of about 50 general chest X-rays. On average, people are exposed to between 1-10 mSv in a year from natural background radiation.

expose people to enhanced levels of radiation – from limited exposure arising from a chest x-ray, through to much larger exposures from a nuclear explosion. Box 7-1 discusses the different biological effects of radiation and how radiation doses are measured. Exposure to ionising radiation can have a range of adverse health effects depending on the extent of damage to the cells of the body as discussed below:

Deterministic effects

Above a certain dose, threshold ionising radiation will kill substantial numbers of cells, giving rise to 'deterministic' effects. The severity of the effects depends on the level of the dose. Examples include damage to body tissues such as the gut, nervous system, and bone marrow (these are symptoms of 'radiation sickness'). At very high doses (e.g. a few thousand millisieverts) these effects can cause death within a short period. Non fatal effects include vomiting and damage to the lung function. When the Chernobyl accident took place, 134 of the 444 workers on-site received sufficiently high doses to suffer from severe radiation sickness.[111] Of these, 28 died within three months as a result of radiation-related injuries. Deterministic effects are not necessarily only short term – for example, cataracts can arise many years after exposure.

Stochastic effects

Even if cells survive exposure to ionising radiation, many cells may then carry mutations in their DNA, which can increase an individual's risk of developing cancer (see Box 7-2). This is referred to as a 'stochastic effect', because the *likelihood* of the effect increases with increasing dose, but the size of the dose will not affect the severity of the disease. For risk assessment purposes it is assumed that there is no threshold below which these effects will not occur – thus even the lowest radiation dose will result in an increased risk of cancer. The delay between exposure and

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[110] http://www.nrpb.org/radiation_topics/risks/exposure.htm

[111] These workers received doses of 700 to 13,400 mSv according to United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), *Exposures and effects of the Chernobyl accident,* 2000. (para 22 and 58).

Box 7-2 Available evidence on cancer risk from ionising radiation

Information on the cancer-causing effects of ionising radiation in humans comes mainly from studies of people exposed to radiation for various reasons – including the Japanese atomic bomb survivors, fallout from nuclear weapons tests and radiation accidents (see section 8.10 for a discussion of the health effects of the Chernobyl accident). Further information comes from people exposed as a result of their occupation, people irradiated for medical reasons, or as a result of environmental exposure to high levels of background radiation (e.g. radon in homes). At higher doses, the extra cancer risk can be detectable using statistical methods. For example, a follow-up of around 90,000 survivors of the atomic bombings of Hiroshima and Nagasaki in 1945, known at the Life Span Study (LSS), indicates that (as of 1997) roughly 6% (536) of cancer deaths were due to radiation exposure due to the explosions (this number will rise as the survivors age). However, at lower doses the extra cancer risk from ionising radiation may not be detectable because so many other factors (e.g. smoking, poor diet) increase the risk of developing cancer.

development of cancer can be as little as two years (in the case of leukaemia) or can be several decades. Another stochastic effect observed as a result of exposure to ionising radiation is hereditary disease in subsequent generations - evidence comes mainly from experiments on plants and animals.

There is also evidence that adverse health effects may be observed in children whose mothers were exposed at the time of pregnancy. This evidence comes from studies of individuals exposed to both low doses[112] as well as high doses of radiation.[113]

7.4 Pathways for exposure of people to radiation

Environmental dispersion of radionuclides

Figure 7-1 illustrates the numerous pathways that radioactive material can take through the environment. Radioactive material can be released in two main ways:

- As a liquid, for example entering the soil or groundwater supplies around a nuclear plant and ultimately entering surrounding water bodies such as lakes, rivers and oceans.
- Directly into the atmosphere in the form of a radioactive 'plume' containing gases and aerosols.[114] This is known as 'atmospheric dispersion'. It depends on many factors, such as weather conditions, the duration of the release, the part of the installation from where it came and the height of the plume above the ground. The amount of heat available at the time of release (e.g. from fire) determines the height of the plume and is therefore a key factor in its subsequent dispersal.

Once released into the environment, radioactive material can move around in a number of ways:

- In and out of the atmosphere - the materials in the radioactive plume would be dispersed and eventually deposited on the ground in a similar manner to smoke from chimneys. Weather conditions greatly influence the distribution of radioactive material. For example, rainfall greatly increases 'fallout', or the removal of radioactive material from the atmosphere, and results in increased levels of activity on the ground. Wind speeds and wind directions affect the areas over which radioactive material is deposited. In general, smaller particles would be carried further before being deposited. Deposited material can re-enter the atmosphere when the ground is disturbed. This is called 'resuspension' and might occur for many reasons such as breezes, traffic, movements of people and animals, ploughing, digging, etc.

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[112] R.Mole, Br. J. Cancer 62, 152-168. '*Childhood cancer after prenatal exposure to diagnostic x-ray examinations in Britain*', 1990.

[113] M.Otake et al., ' *Effect on school performance of prenatal exposure to ionizing radiation in Hiroshima*' , Radiation Effects Research Foundarion report TR2-88, 1988.

[114] An aerosol is a suspension of solid or liquid particles in the air; typical dimensions range from less than 1 micron to over 100 microns.

- Water sources (rivers, oceans, lakes and streams) - radioactive material in the atmosphere can be deposited directly onto water surfaces. Also, rain flowing through contaminated land can transport radioactive material into rivers, oceans and lakes. Radioactive material can then be transported by water from one area to another. Some elements, such as technetium-99 (generated mainly by reprocessing) are particularly mobile in the marine environment - trace quantities of technetium from Sellafield have been found off the coast of Scandinavia and further afield.[115]
- Living things: as mentioned previously, radionuclides can be deposited on the surfaces of vegetation which can then be consumed by people or by animals (e.g. livestock). The milk and meat from these animals may then contain additional radioactivity.[116] Alternatively radionuclides deposited on the ground can be transported through the soil and can enter the roots of plants and trees, etc. These plants can then be consumed or put to other uses by humans (e.g. burning for fuel).

The path a radioactive material takes through the environment and its subsequent environmental and health impact depend on the properties of the particular radionuclide:

- The **half-life** of a radionuclide affects the length of time that it poses an environmental and health risk following its release. For example, in the first few weeks following the Chernobyl accident, most exposure to radiation was due to iodine-131, a short-lived radionuclide with a half-life of eight days. However, after this initial period, the main contribution to the radiation dose was from caesium-137, which has a half-life of several decades and still makes a significant contribution to the radiative dose in some areas.[117]
- The **type of ionising radiation** emitted influences the health effects associated with a radionuclide. For example, alpha particles cannot penetrate the skin, but can cause considerable damage if they are emitted *inside* the body. Most isotopes of plutonium are alpha-emitters and are therefore mainly harmful if inhaled or ingested (Box 7-3). However, beta and gamma radiation (emitted by radionuclides such as caesium-137) can penetrate the skin, and can therefore contribute to dose effects even if emitted *outside* the body, for example if radionuclides are deposited on the ground or on the surfaces of buildings.
- The **daughter products** of a radionuclide (i.e. the new radionuclides produced from the decay of the original radionuclide) are also important – for example, plutonium-241, an isotope of plutonium which is a beta emitter, is mainly a health hazard because it decays into americium-241, an intense gamma emitter.
- **Physical and chemical properties** are important in determining the extent to which a given radionuclide is released and its subsequent movement through the environment. Following a nuclear accident, radionuclides would mainly be released either in gaseous form, or as fine particles. 'Volatile' radionuclides would be released in greater proportions than non-volatile ones.[118] The solubility of a radionuclide will determine, for example, the extent to which it contaminates water supplies, or the length of time it remains in soil.
- **Retention by the human body**: the longer an element is retained by the human body, the greater the internal dose received. For example, a noble gas (e.g. Xenon, Krypton) does not readily undergo chemical reactions and so is simply breathed in and out. On the other hand, some forms of plutonium can enter the blood stream via the lungs and can be retained in

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[115] See http://www.defra.gov.uk/environment/radioactivity/discharge/sellafield/ . A full discussion of the controversial issue of technetium-99 discharges from Sellafield is beyond the scope of this report.

[116] i.e. in additional to natural background concentrations of radioactive material.

[117] Certain pathways through the environment, such as uptake via the roots of a plant, which can take several weeks, are less important for shorter lived radionuclides such as iodine-131 – although this clearly depends on the initial concentrations of the radionuclide.

[118] A volatile substance is one which is capable of readily changing from solid or liquid form to a vapour.

bone marrow and other organs. Similarly, caesium is retained in muscle tissue and has a 'biological half-life' (see glossary) of six months.

Modes of exposure

People can be exposed to radioactive material released into the environment by two main routes:

- Inhalation - breathing in radioactive particles on the air.
- Ingestion – drinking affected water, or eating affected food – e.g. plants, or milk/meat from animals that have eaten these plants. This was one of the main routes of exposure after the Chernobyl accident.
- Contact - even if radioactive material does not get inside the body a dose can be received if it gets on the skin, although this depends on the kind of radionuclide (see next section).
- Irradiation - even if radioactive material does not enter the body or get on the skin, people can still be exposed to radiation emitted by radioactive material on the ground ('ground-shine') or in the atmosphere ('cloud-shine').

There are hundreds of different radionuclides associated with the activities discussed in chapters 2 and 3. It is beyond the scope of this report to discuss all of these in detail. Box 7-3 discusses the properties of some of the key radionuclides associated with nuclear fission.

7.5 Protecting the public in the event of a radioactive release

The radiation dose received by a member of the public would depend on actions taken following a release. In the UK, the National Radiological Protection Board[119] (NRPB) is responsible for providing guidance on possible responses to a release of radionuclides so as to minimise health effects. The main options for protecting the public in the event of a release are sheltering indoors, evacuation, administration of iodine tablets, restriction of the consumption of food and water, relocation, and decontamination of affected material such as land and buildings.[120] Decisions about which of these actions are appropriate need to balance the harm caused by the countermeasure against the harm averted by avoiding exposure to radiation.

The NRPB gives guidance on when to introduce each countermeasure, based on the radiation dose that could be avoided if that countermeasure were taken through setting emergency reference levels or ERLs (Box 7-4). The guidance allows emergency planners the flexibility to exercise their discretion in responding to particular events. One of the key factors in determining the appropriateness of an action is the difficulty of undertaking the measure.

The 'harm' resulting from a countermeasure is taken to mean not only exposure to radiation but also mental health (anxiety) and wider issues such as economic cost and social disruption. So, for example, sheltering indoors with windows and doors closed for a few hours or days immediately following a release would cause much less overall disruption than evacuation. As a result, although prompt evacuation has the potential to prevent virtually all exposure to a release, the thresholds for using this countermeasure are set at a higher level than for sheltering. Dose thresholds are discussed further in Chapter 11, which focuses on emergency planning.

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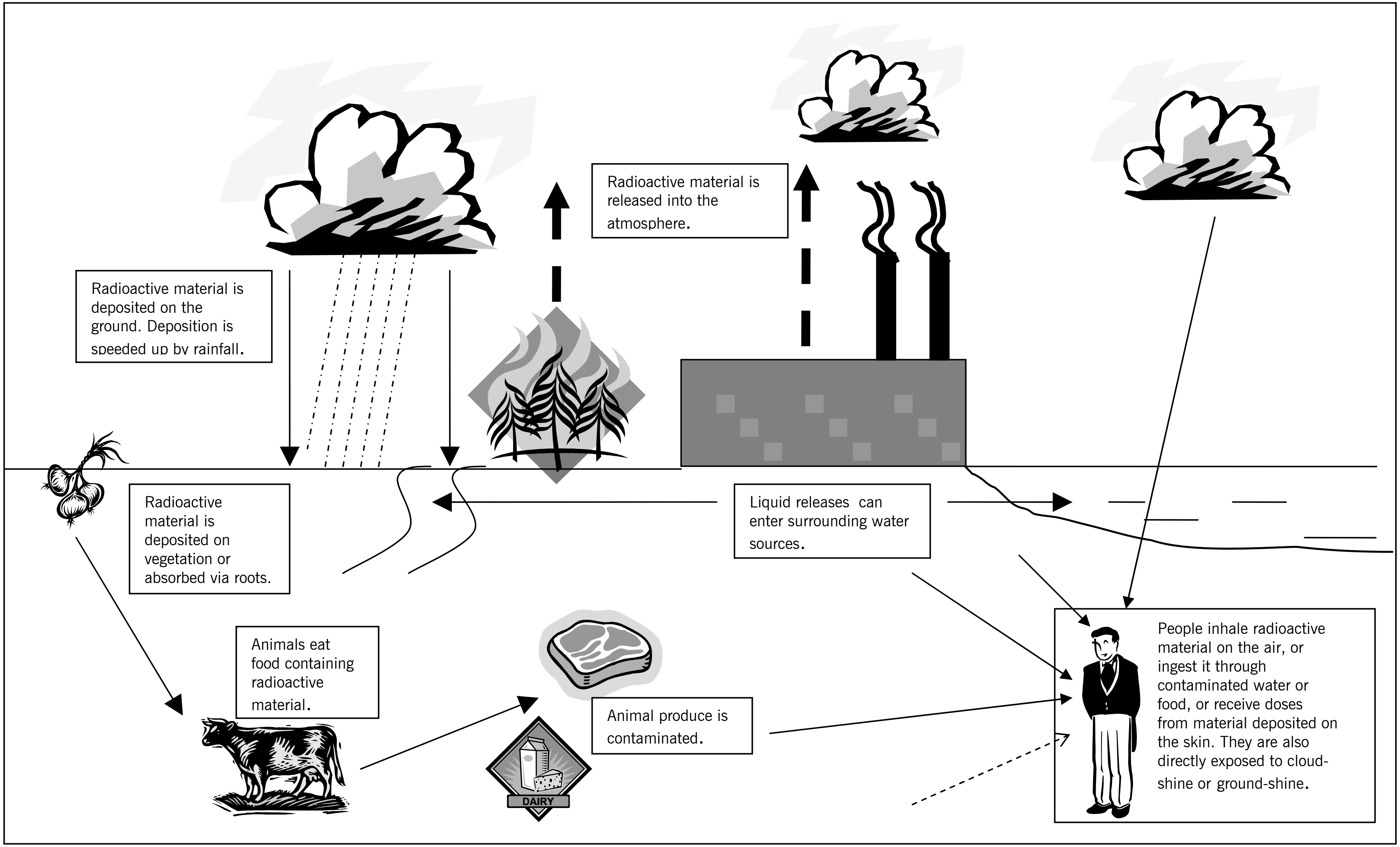
[119] Working in partnership with the Health Protection Agency (see Box 2-5).

[120] Iodine tablets contain potassium iodide, which is absorbed and retained by the thyroid gland, thus limiting subsequent absorption of radioactive iodine.

Figure 7-1 Pathways for exposure to ionising radiation.



Box 7-3 Properties of key radionuclides associated with nuclear fission

Iodine and caesium are discussed below as they would probably make the largest contribution to doses received by the public following a release from a nuclear reactor. Transports of nuclear weapons and special nuclear materials mainly involve uranium and plutonium, which are also discussed below.

Iodine

Radioactive iodine is produced in nuclear reactors by fission of uranium. It is volatile (readily turns into a vapour) and can be released as a gas, an aerosol or dissolved in water. One of the most important radioactive isotopes that escaped after the Chernobyl accident was iodine-131 (I-131), which has a half-life of eight days. Because of this short half-life, I-131 release is mainly a risk for operational nuclear reactors and is not a key component of spent fuel (unless it has very recently been removed from a reactor) or radioactive waste. Another important isotope is I-129, also produced by nuclear fission, and has a half-life of millions of years. Most of the I-129 in the environment comes from weapons testing.
Radioactive iodine is harmful to human health because the body cannot distinguish it from normal iodine. It collects in the thyroid gland and irradiates the thyroid. Radioactive iodine has therefore been linked to thyroid cancers, particularly in children. Most of the off-site exposure which occurred in the first few weeks after the Chernobyl accident was due to consumption of milk from animals that had eaten leafy plants contaminated with I-131.

Caesium

Caesium is produced by the fission of uranium and is volatile, like iodine. There are two main radioisotopes: caesium-137 (half-life 30 years) and caesium-134 (half-life two years). If caesium is deposited on the ground, it can be absorbed by the roots of plants and trees, which then become contaminated and can in turn be consumed by humans or animals. This was one of the contributing factors to the long term radiation dose received by exposed populations after the Chernobyl accident.

Plutonium

Plutonium is produced from uranium in nuclear reactors. It is non-volatile and is not released as readily as volatile elements like iodine and caesium. It is most likely to be released as fine particles of plutonium oxide via fire or explosion. There are several different radioactive isotopes of plutonium, some of which have half-lives of tens of thousands of years and can therefore pose an environmental hazard over very long time scales. Radioactive plutonium is extremely hazardous once inside the body although it does not pose a major health hazard outside. Inhalation of plutonium is more hazardous than ingesting it. The main risk to human health from dispersal of plutonium is an increased risk of developing cancer. It is estimated that inhalation of 0.1 milligram (one ten-thousandth of a gram) of 'respirable' plutonium[121] would greatly increase the risk of developing lung cancer. Like uranium, plutonium is a toxic metal and may cause damage to the kidneys, but this is not as important as the radiological consequences.

Uranium

Uranium is naturally occurring. It is a heavy metal like plutonium, and is also non-volatile. The principal radioisotope in uranium is uranium-238. Although the risk to human health from uranium is not comparable with that posed by plutonium, it is still hazardous if it gets inside the body because it is a toxic metal. It is also weakly radioactive and therefore poses an increased risk of cancer. There is evidence of a link between uranium intake and cancers in animals but there is considerable uncertainty involved in extrapolating these data to evaluate the risk to humans.[122]

Others

There are many other non-volatile radionuclides found in irradiated nuclear fuel and associated materials (e.g. high level waste) although they are likely to make smaller contributions to radiation doses after a release than iodine or caesium. These include radioactive strontium, which was one of the main causes of contaminated water after the Chernobyl accident. Strontium acts like calcium and concentrates in bones and teeth, thus increasing the risk of bone cancer.

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[121] 'Respirable' particles is used here to refer to particles less than a few thousandths of a millimetre across. Larger particles are not as easily absorbed when inhaled.

[122] http://www.ieer.org/fctsheet/uranium.html

Box 7-4 Emergency reference levels (ERLs)

Based on an estimate of the effective dose that could be avoided by implementing a particular countermeasure, the NRPB sets a lower and upper emergency reference level (ERL). Below the lower ERL, the NRPB judges that introduction of the countermeasure would not be justified because of the harm that it would cause. The upper ERL is the dose level at which the NRPB expects every effort to be made to introduce the countermeasure, except in exceptional circumstances. It is set at ten times the dose of the lower ERL. Between the two, emergency planners have the freedom to exercise their discretion.

The lower and upper ERLs for sheltering are a dose of 3mSv and 30mSv respectively. For evacuation, they are 30mSv and 300mSv. These are higher than the recommended dose limit for routine exposure, which is 1 mSv per year for the public. This is because the ERLs are not intended to represent the boundary between what is 'safe' and what is 'unsafe', but to represent an acceptable balance between the harms and benefits of an action.

7.6 Modelling the consequences of a release

Current understanding of the off-site consequences of accidents at nuclear facilities (which could provide some indication of the consequences of a deliberate attack) is based on computer simulations. Data from actual observations (e.g. the Chernobyl accident) also allow further understanding of the processes involved. Models have two main functions:

- **Emergency response tools** - for use after an accident has occurred – e.g. to perform functions such as predicting the path of a radioactive plume, to optimise the effectiveness of countermeasures.
- **Pre-planning tools** - to predict the consequences of theoretical accidents, for risk assessments, emergency planning and design purposes.

Predictions vary widely, particularly in the case of pre-planning, depending on factors such as:

- Uncertainties in the 'source term' – i.e. in the size and nature of the initial release.
- Natural variability in the environment – for example, the outcome of a simulation can vary greatly depending on assumptions made about weather patterns.
- Assumptions made about contingency planning arrangements - the actual dose received by a member of the public in the event of a release will depend on what countermeasures were taken and how effective they are.

There are also uncertainties arising from incomplete understanding of the impact of radionuclides on the environment and on human health. While such uncertainties are smaller than those described above, any simulation must necessarily make some simplifying assumptions, and its output is only indicative of a potential outcome rather than a true picture of an event.

Types of assessment

Simulations can be used in two distinct ways:

- **Probabilistic assessment** takes into account a range of different starting conditions – e.g. different possible values of the source term, or different possible atmospheric conditions. Each set of conditions is weighted according to its likelihood of occurrence. The final output is a weighted average of all the consequences of all these different input conditions.
- **Deterministic assessment** involves investigating the consequences of a specific scenario - e.g. a particular set of weather conditions.

Box 7-5 The COSYMA model for predicting the radiological consequences of a release[123]

COSYMA is a computer program widely used in the European Union for assessing the off-site radiological consequences of accidental atmospheric releases of radioactive material. It was developed jointly by the NRPB and the FZK (Forschungszentrum Karlsruhe, Germany) with support from the European Commission's Radiation Protection Research Programme during the late 1980s.

Input
The user must provide a range of input information – e.g. on the characteristics and size of the release, its location, atmospheric conditions, countermeasures adopted and the population distribution around the site. The package also includes data libraries – e.g. data on radiation doses received from exposure to different kinds of radionuclides.

Output
The COSYMA package provides output information on:

- air concentration and deposition, both at specific locations and as a function of distance from the site.
- numbers of people and areas affected by countermeasures over time.
- amounts of food banned.
- the duration of countermeasures at particular locations.
- the probability of implementing countermeasures, both at specific locations and as a function of distance from the site.
- doses received in selected time periods, both at specific locations and as a function of distance from the site.
- the individual risk of early and late fatal and non-fatal health effects, both at specific locations and as a function of distance from the site.
- the numbers of early and late fatal and non-fatal health effects.
- the economic costs of the off-site consequences of an accident.

Emergency response tools are based on deterministic techniques and are designed to incorporate real weather conditions, but pre-planning tools use both deterministic and probabilistic techniques.

Commonly-used computer models
There are many computer programs available to simulate the off-site radiological consequences of a release. All models consist of a number of different modules, each of which deals with a specific component of the problem – for example, modelling atmospheric dispersal, the re-suspension of radionuclides, or the external radiation dose people receive. In the EU, the COSYMA model is commonly used in pre-planning (although it is not suitable for emergency response). A brief discussion is provided in Box 7-5 to illustrate how such models work.[124]

Consequence analyses carried out by operators
In the UK, 'consequences analyses' are carried out by nuclear operators as required by the *Safety Assessment Principles for Nuclear Plants* (SAPs - section 3.4),[125] but the analysis does not have to be as detailed for severe accidents as for design-basis accidents. For a severe accident, the SAPs state that the analysis '*should determine the magnitude and characteristics of the radiological consequences*' and should also '*provide information relevant to the preparation of the site emergency plan for the protection of people outside the site in the event of a large release of radioactivity*'. Some of the analyses carried out for public inquiries into the construction of Sizewell B, the proposed C reactor at Hinkley Point, and the THORP[126] reprocessing plant at Sellafield, are publicly available. Very little else is published and there is little information on what studies are currently underway. To carry out a detailed consequence

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[123] http://ant.inep.ksc.ru/ineplab24/ocb/page/4.htm

[124] This was developed jointly by the NRPB and the ForshungZentrum Karlsruhe, Germany, as part of a European Commission project in the late 1980s. See http://www.nrpb.org/publications/software/cosyma/

[125] Health and Safety Executive, *Safety Assessment Principles for Nuclear Plants* (principle 48).

[126] THORP stands for 'Thermal Oxide Reprocessing Plant'.

analysis, information on source terms would be required, but for all UK installations except Sizewell B this information is not made public.[127]

The NRPB is the main independent advisory body in the UK with expertise on radiation hazards. However, it does not currently have a research programme to investigate the off-site consequences of severe accidents or terrorist attacks at nuclear installations. The NII also has expertise in this area. It regularly tests the nuclear industry's emergency response plans and it has a specialist unit to deal with security related issues.

Some specific examples of consequence analyses are discussed in the next three chapters.

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[127] The IAEA has a programme of work in the area of severe accidents and accident management at nuclear power plants. This work focuses on on-site management of the consequences of severe accidents (see Chapter 11), rather than evaluation of the off-site consequences of such events.

8 Reactors

8.1 Key points

- The main inventories of radioactive material at a nuclear power plant are in the reactor core and in the spent fuel cooling ponds. Radioactive material might be released via a direct attack which breached the containment around these structures, or an indirect attack, which damaged enough critical safety systems to bring about a release.
- Because of defence in depth, a ground-based attack would need to be highly co-ordinated and would require detailed site-specific knowledge of plant operations and design.
- Most published reports focus on direct attack via aircraft impact and reach differing conclusions about whether such an attack could bring about a large release of radioactive material, either from a reactor core or a spent fuel cooling pond, depending on factors such as the type of reactor, the type of aircraft considered and the speed and angle of the impact.
- Because of specific design features, the UK's three oldest operational Magnox reactors may be more likely to sustain physical damage than other UK reactors, in the event of an attack. These plants are all scheduled to cease operating by 2006. More detailed studies would be needed to draw general conclusions on the relative vulnerabilities of gas-cooled reactors and PWRs.

8.2 Introduction

The hazard posed by a given nuclear facility is influenced by a number of factors. Its size, location and surroundings will affect the feasibility of certain modes of attack. Its physical robustness will determine how much damage it could sustain. The physical properties of the radioactive material it contains, such as whether it is a solid or a liquid, or whether it requires active cooling, will determine how easily it is dispersed. Also, the quantity and type of radioactive material in the facility and the distance from major population centres will affect the environmental and public health consequences of any release.

As explained in Chapter 1, there is a wide range of different types of nuclear facilities in the UK and surrounding countries As it is not possible to review the vulnerability of the entire range, this report reviews what is known about the following specific activities, each having various different types of nuclear facility associated with them. The selection is based on the above factors, as well as on the degree of public concern associated with their operation.

- Civilian nuclear reactor sites (nuclear reactors and spent fuel storage).
- Civilian reprocessing facilities: (reprocessing facilities, high level waste storage, plutonium storage and spent fuel storage).
- Shipments of radioactive material (focussing on the rail transport of spent fuel).

This chapter focuses on nuclear reactors and their vulnerability to terrorist attack. Nuclear reactors have a range of applications in addition to civilian nuclear power, including use in nuclear submarines, in research and in the production of radioisotopes. This section focuses mainly on civilian nuclear power plants, as these contain the largest inventories of radioactive material, although there is some discussion of research reactors.

Section 8.3 provides background information on how nuclear power reactors work and section 8.4 outlines safety features which may affect their robustness against terrorist attack. Section 8.5 then describes different designs of nuclear power reactor, focussing on those in the UK. Sections 8.6 and 8.7 then discuss the kinds of scenarios (both deliberate and accidental) that might occur at nuclear reactors, which could result in a release of radioactive material. Some vulnerability assessments carried out by overseas authorities are described, although reactor designs vary considerably in different countries, so these assessments cannot be used to draw conclusions about UK nuclear power reactors. Section 8.8 provides a brief overview of commentary on the potential for terrorist attacks on research reactors. Sections 8.9 and 8.10 discuss what is known about the potential consequences of sabotage, with reference to modelling studies of accidents at the Sizewell B power plant and data from the Chernobyl accident. Section 8.11 discusses the storage of spent fuel at reactor sites.

8.3 Nuclear reactors - background

How power reactors work

All nuclear reactors contain a core of 'fissile' material in which a nuclear fission chain reaction takes place under controlled conditions (see Annex 1). The heat produced by this reaction is extracted from the reactor core by means of a coolant (which can be a liquid or a gas). In a power plant, the heat from the coolant is then used to generate steam, which drives turbines to produce electricity. There are many different variations on the basic reactor design, which are described in the box on the next page. However, all power plants have the same basic features in common:

- **Fuel** - most nuclear power plants use fuel based on either natural uranium or low enriched uranium (LEU). The fuel is in the form of 'fuel elements' – fuel encased in a metal tube which acts as 'cladding' and helps to contain the radioactive products of the nuclear reaction. A typical PWR power plant contains around ~100 tonnes of fuel in its core (in thousands of individual fuel elements). This figure can be higher for a gas-cooled reactor.
- **Control rods** - the fuel elements are interspersed with 'control rods' which are used to control the rate of the nuclear reaction in the core. They are made of a material which absorbs the neutrons needed to sustain the chain reaction (as explained in Annex 1). In most cases the control rods are lowered into the reactor core from above so that the rate of the reaction can be controlled by altering the position of the control rods. Additional 'shut down' rods are held out of the core and in the event of an accident they should drop into the core under gravity and stop the nuclear reaction.
- **Moderator** - this is a material such as graphite or water, which is incorporated into a reactor core to keep the nuclear chain reaction going. If the moderator is lost (e.g. through evaporation in the case of water) the chain reaction ceases. Moderators are used in all 'thermal reactors' where the neutrons produced by nuclear fission move too fast to keep the reaction going and must be slowed down. All modern commercial reactors are thermal.
- **Coolant** - this can be a gas such as carbon dioxide, or a liquid such as water. The coolant is pumped around the reactor core in what is referred to as the 'primary coolant circuit'. In most reactor designs the coolant is used to heat water in a 'secondary coolant circuit', converting it into steam to drive the turbines.
- **Pressure vessel** - this is a steel or concrete vessel which contains the reactor core – i.e. the coolant, the moderator (gases or liquids at high pressure) and the fuel rods.
- **Heat exchanger** (also known as the steam generator or boiler) - this is the part of the cooling system where the heat from the coolant is extracted to heat water and used to generate steam.
- **Turbines** - the steam produced drives turbines which are used to generate electricity (as with non-nuclear power plants).
- **Condenser** - this turns steam from the turbines back to water, so that it can be re-used.
- **Containment** - some types of reactor (e.g. pressurised water reactors) have containment structures made of steel or concrete, which surround the reactor pressure vessel and other essential systems, and are designed to be robust enough to withstand a range of accident scenarios.

Buildings at a nuclear power plant

The specific layout of nuclear power plants varies depending on the type of reactor as well as when the plant was constructed and where it is located. In general, all reactors have the following buildings:

- **reactor building**- for housing the reactor pressure vessel and cooling systems.[128] The reactor control room is often located within the reactor building or in an auxiliary building annexed to the reactor building.
- **fuel store** - for storage of new reactor fuel.
- **cooling ponds** - for underwater storage of used reactor fuel.
- **turbine hall** - for the steam turbines, main generators and condensers.
- **switchyard** - for the electrical connections between the power station output and the transmission grid.
- **waste treatment and storage facilities**: for handling both low and intermediate level waste. In the UK, most ILW is stored at Sellafield, in Cumbria. LLW is transported to Drigg (also in Cumbria).

8.4 Reactor safety

Under normal operating conditions a reactor core will be at temperatures of several hundred degrees Celsius. Safety features are therefore necessary both to prevent accidents occurring and to minimise the exposure of workers and the general public to radiation in the event of an accident, as discussed in Chapter 3. Safety systems vary depending on the plant design, with modern plants having more inherent safety features than older ones (particularly those in the Former Soviet Union – see Box 8-1). The safety of a nuclear reactor is broadly based on three key principles: controlling the reaction, cooling the reactor core, and containing radioactive material.[129]

Controlling the reaction

The condition of the reactor is monitored from the control room which is permanently staffed. The reaction can be speeded up or slowed down by raising or lowering the control rods. In addition, reactors are closely monitored by safety circuits and any abnormalities should trigger automatic shutdown of the reactor by lowering the control rods into the reactor core. Secondary and tertiary shutdown mechanisms also exist - for example in an AGR, the secondary shutdown system involves injecting nitrogen into the reactor, to stop the nuclear chain reaction.

Cooling the reactor core

The main hazard envisaged is overheating of the reactor core, which could result in damage to it, leading to release of radioactive material. The circulation of coolant in both primary and secondary coolant circuits must therefore be maintained and coolant temperature and pressure must be regulated. Even when a reactor shuts down and the fission reaction stops, the core continues to generate 'decay heat' as a result of radioactive decay of fission products. This can amount to as much as 10% of the heat generated during normal operation. Therefore, reactors are equipped with cooling systems to remove this 'decay heat' in the event of shutdown.

Containing radioactive material

A series of physical barriers is in place to prevent release of radioactive material:

- the uranium fuel matrix (i.e. the ceramic fuel pellets, used in all UK commercial reactors except Magnox) which contains most of the fission products.

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[128] With the exception of Sizewell B which has a single reactor, and Chapelcross and Calder Hall, which have 4 reactors, all other nuclear power stations in the UK have two reactors, which are either housed in two separate reactor buildings or in the same building.

[129] As outlined in Hewitt and Collier, *Introduction to Nuclear Power,* published by Taylor and Francis, 2000.

- the metal cladding on the fuel elements, which is designed to prevent the fission products contaminating the coolant, and to prevent the uranium fuel from coming into contact with the coolant.
- the pressure vessel, which contains the reactor core, the primary coolant and the moderator. In some modern gas-cooled reactors (see next section) the pressure vessel also contains other essential equipment such as the heat exchangers.
- the reactor building itself. This can be either a normal industrial building or a more robust building, depending on the type of reactor (see next section).

As explained in Chapter 5, the key principles used to ensure safety are redundancy, diversity and segregation. Thus modern plants have multiple systems which perform the same function (e.g. shutting down the reactor, removing heat from the reactor, or supplying power) in different ways.

8.5 Reactor designs

Nuclear reactors worldwide

Box 8-1 discusses the different designs of nuclear power reactor in operation today. The majority are pressurised water reactors or PWRs (see Figure 8-1) and use water as both moderator and coolant. As of March 2004, there were 440 nuclear power reactors in operation at nuclear power plants worldwide, with a further 63 planned or under construction.

Power plants in the UK

There are three different designs of power plant operational in the UK - there are 12 gas-cooled power stations (5 Magnox and 7 AGR) with 26 operating reactors, and one PWR. In addition, there are three decommissioned Magnox plants, scheduled to be defuelled over the next few years (between 2005 and 2007). These plants are listed in Table 1, Annex 2. There are two key features distinguishing gas-cooled reactors from PWRs – the size of the reactor core (and hence the energy per unit volume) and the containment systems. These two factors potentially have implications for the consequences of a terrorist attack.

Reactor size

The ‘power density’ (i.e. power per unit volume) of a PWR is several times higher than that of an AGR (Figure 8-2), which is in turn ten times higher than with a Magnox reactor. Thus, depending on the type of reactor and its power output, a gas-cooled reactor can have a core over 30 times the volume of a PWR. Thus a PWR core would heat up faster following a loss of coolant, allowing less time for remedial action to be taken. For example, at Three Mile Island (Box 8-3) damage to fuel elements had occurred within three hours of the initial fault.

Reactor containment

In a PWR, the reactor pressure vessel and associated systems are housed within a dome-shaped concrete containment structure ~70 m high and over a metre thick, which is designed to be robust enough to withstand a range of accident scenarios. In addition, the PWR pressure vessel itself is shielded by a concrete ‘biological shield’ over a metre thick, designed to prevent exposure of workers to harmful levels of ionising radiation.

Box 8-1 Nuclear reactors[130]

Commercial nuclear power plants

- *Pressurised water reactors (PWRs)* are the most common type of reactor and are used both in civilian power generation and in naval propulsion. PWRs are more compact than gas-cooled reactors. They use enriched uranium dioxide fuel in pellet form, clad in zirconium alloy. The fuel in the reactor vessel is both cooled and moderated by normal 'light' water, held at high pressure to stop it from boiling. This water is circulated within a 'primary pressure circuit' and its heat is extracted by means of a 'secondary pressure circuit' containing water at lower pressure, which boils as it is heated. Pressurised Heavy Water or CANDU reactors use natural uranium as a fuel and heavy water as a moderator and coolant.
- *Boiling water reactors (BWR)* are similar to PWRs but the design is simpler. The water is circulated at lower pressure in a single circuit, so that it boils within the reactor pressure vessel itself. Since water around the core of a reactor becomes contaminated with traces of radionuclides, the steam turbines can also become contaminated and must be shielded. PWRs and BWRs which use light water rather than heavy water are referred to as Light Water Reactors or LWRs.
- *Magnox reactors* were the first generation of gas-cooled reactors to be developed commercially in the UK.[131] They use natural uranium metal as fuel and graphite as moderator. The fuel is in the form of fuel rods clad in magnesium alloy and inserted into graphite blocks. The coolant used is carbon dioxide gas under pressure, which circulates in a closed loop, removing heat from the reactor core and then passing through a boiler which extracts the heat from the coolant to raise steam. The use of natural uranium as the fuel and graphite as the moderator means that there is a practical limit to size of the core and hence to power generation. Also, the use of a metallic fuel limits the operating temperatures to around 400 degrees Celsius, which limits the thermal efficiency of the power station.
- *Advanced Gas-cooled Reactors (AGRs)* followed on from Magnox. They are similar to Magnox reactors, but are more efficient as power plants, as they use enriched uranium as a fuel in the form of uranium oxide pellets contained in stainless steel tubes. This enables the reactor core to be much smaller and allows the fuel to operate at higher temperatures.
- *Fast Reactors* rely on fission from fast neutrons, so they do not need a moderator and hence the power generated per unit volume is very high. They were originally designed not only to generate power but also to breed more fissile material than they consume ('Fast Breeder Reactors') and therefore make efficient use of uranium. The UK and many other countries had FBR programmes throughout the 1970s and 1980s but most of these have been terminated, principally for economic reasons. However, fast reactors can also be configured to consume plutonium ('Fast Burner Reactors'). There are only 4 fast reactors worldwide (in France, Japan and Russia).
- *Advanced reactors* are new reactor designs which incorporate more passive safety systems and/or more advanced technology to provide increased control and protection. Most reactors in operation are 'Generation II' reactors built in the 1970s and 1980s, so these new designs are sometimes categorised as 'Generation 2.5' or 'Generation III' and are just beginning to operate in various countries. Advanced boiling water reactors are operating in Japan, four 'N4' type reactors are in operation in France and several more are under consideration in Japan. Finland has recently made a decision to construct one 'European Pressurised Water Reactor' (EPR) and decisions are expected shortly on new EPR build in France. There are no advanced reactors operating or planned in the UK.

The following are reactor types developed in the Former Soviet Union (FSU):

- *VVER reactor*s are PWRs. The initial designs were low power and did not have reactor containment buildings. The later and larger power designs are similar to western PWRs with containment buildings. VVER reactors are still in operation in the FSU as well as in some other Eastern European countries (e.g. Hungary, Bulgaria, and the Czech Republic) and in Finland.
- *Light Water Cooled Graphite Moderated reactors (RBMK)* such as the reactor involved in the Chernobyl accident, were originally developed to produce plutonium for military use. They use graphite as a moderator and normal water as a coolant and have pressure tubes rather than a pressure vessel.

Many of the older reactors in the FSU, particularly the RBMKs, have serious design deficiencies which make them inherently less safe than 'Western style' reactors. A considerable amount of international effort is focussed on improving their safety characteristics. As of February 2004 there were 14 RBMK reactors in operation in Russia.

Naval Propulsion Units

There are also ~160 nuclear submarines operational worldwide and a small number of military nuclear-powered ships. The propulsion units are based on the PWR design, but are much smaller and use a slightly different fuel.

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[130] Main source: World Nuclear Association.

[131] 'Magnox' stands for 'Magnesium no oxidation'.

Figure 8-1 Diagram of a pressurised water reactor (PWR)

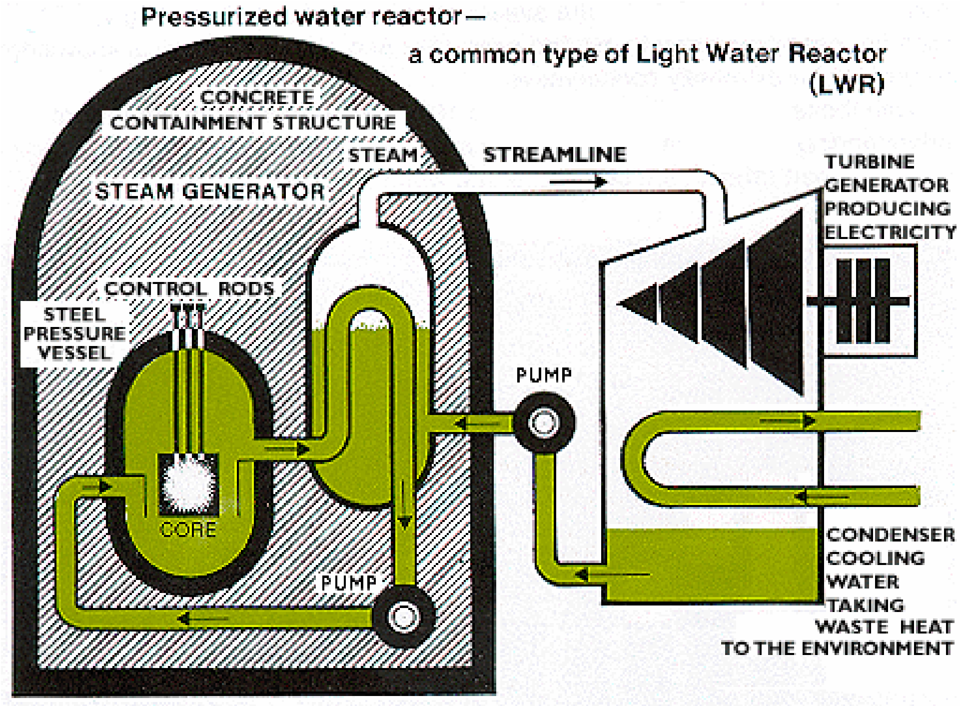
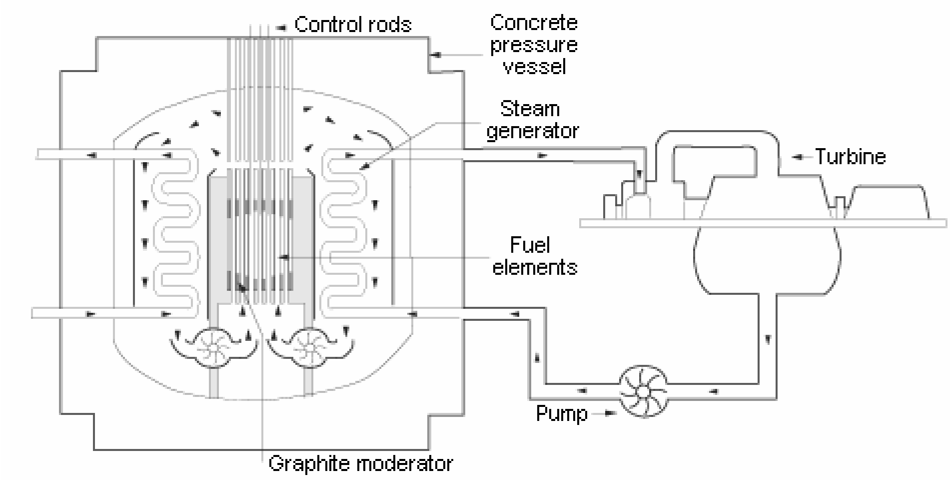


Figure 8-2 Diagram of an advanced gas-cooled reactor (AGR)



Source: World Nuclear Association

Gas-cooled reactors do not have an external containment building – the reactor building is a normal industrial building.[132] However, in the UK's AGRs and later Magnox reactors, the pressure vessel (roughly twenty metres across) is made of pre-stressed concrete several metres thick, and the boilers are located within this.[133] It therefore provides containment as well as acting as a biological shield (see section 5.3).

Power plants in France and Belgium

All the operational power reactors in France and Belgium are PWRs, with the exception of one Fast Breeder Reactor at Phenix in France, scheduled for shutdown in 2007.

8.6 Accidents at nuclear reactors

It is useful to discuss accident scenarios when considering the robustness of nuclear plants to terrorist attack, because the same sequence of events may occur as a result of a given initiating fault, whether it is deliberate or accidental. A range of accident scenarios can be envisaged at nuclear power plants as a result of component failure, operator error, external and internal hazards, or a combination of these factors. The NII states that, in accordance with the Safety Assessment Principles for Nuclear Plants (see Chapter 3), reactors are designed so that accident scenarios that can have serious consequences have a very low probability of occurrence. A severe accident causing significant damage to the reactor core could occur only if several systems are damaged or disabled simultaneously and would cause a release only if all the containment systems were breached.

Design basis accidents

Plants must be designed to cope with a range of accidents, decided according to their predicted accidental frequency of occurrence. Some examples of design basis accidents are listed below.

- Small 'loss of coolant' accident.
- Station blackout – loss of grid connection in association with loss of emergency generators.
- Internal hazards – e.g. fire, floods.
- Steam generator tube rupture.
- Depressurisation: i.e. loss of coolant pressure.[134]

In any of these situations, the SAPs stipulate that the general public should not be exposed to levels of radiation above permitted limits.[135]

Beyond design basis accidents

A beyond design basis accident is one that is predicted to occur so infrequently that the plant is not specifically designed to cope with it, although it may possess some capability to mitigate the consequences were the accident to occur. Examples of severe accidents, where several different systems fail simultaneously, leading to disruption to the cooling system and to overheating of the reactor core include:

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[132] The NII state that, in the case of PWRs, an external containment building is required because it is assumed that the first three containment barriers could be breached during a design basis accident, releasing fission products. However in the UK's gas-cooled reactors have lower power densities and the coolant does not change phase (i.e. change from liquid to gas) under loss of pressure, hence the first three barriers are generally assumed to remain intact under the design basis faults and an external containment building is not required.

[133] For AGRs the inside of the pre-stressed concrete pressure vessel is lined with steel.

[134] In the event of depressurisation heat would not be removed as effectively which could potentially lead to core overheating and core damage. However, in such an eventuality the reactor should automatically shut down and emergency core cooling systems should remove the excess decay heat and prevent serious core damage.

[135] The maximum permissible dose for a member of the public following a Design Basis Accident, as specified in the Safety Assessment Principles, is 100 mSv.

Box 8-2 Severe accidents at PWRs and gas-cooled reactors

Severe accident scenarios at nuclear reactors are associated with disruption to the cooling system leading to overheating of the reactor core. The consequences of such an event depend on the type of reactor in question and what remedial action is taken. Likely courses of events at PWRs and gas-cooled reactors are discussed below.

PWRs

In a PWR, overheating would lead to damage to the fuel elements as a result of the expansion of gaseous fission products and changes in material properties. This would lead to swelling and rupture of fuel element cladding, thus further inhibiting the flow of coolant. In addition, steam would be produced in the pressure vessel. If temperatures continued to increase, the zirconium cladding on the fuel could interact with this steam, releasing additional heat and also generating hydrogen. The fuel cladding and supports could then collapse, leading to a 'core meltdown' situation in which a mass of molten material would slump down to the bottom of the reactor pressure vessel. This, or in the worst case scenario, the reactor containment, could then be damaged as a result of interactions with the molten core or as a result of steam explosions or hydrogen explosions. Damage can occur fairly rapidly if remedial action is not taken. For example, at the Three Mile Island accident in 1979, which is the worst accident at a PWR to date, coolant slowly leaked from an open valve and damage to fuel elements had occurred within three hours of the initial fault.

Gas-cooled reactors

At a gas-cooled reactor, temperatures would rise more slowly than at a PWR following a loss of cooling. This is because gas-cooled reactor cores are larger and therefore have a lower 'power density' (see previous section). In addition, the large mass of graphite in the core of an AGR or Magnox reactor absorbs heat thus slowing down the rate at which the fuel elements overheat. The design of gas-cooled reactors is said to be such that if coolant circulation were lost (e.g. in the event of a loss of power to the gas circulators) and emergency shutdown took place, natural circulation would provide sufficient cooling to prevent any damage to the reactor core. In such a situation, the probability of core meltdown in a gas-cooled reactor is much lower than for a PWR. In fact, the nuclear industry claims that total fuel meltdown cannot occur at a gas-cooled reactor (as long as the system remains sufficiently intact to allow natural circulation of coolant). Note that under severe accidents, there is the potential for fires in the graphite of the reactor core. Furthermore, Magnox cladding will ignite and burn under certain circumstances.

- Loss of coolant combined with loss of all emergency coolant systems.
- External hazards – e.g. severe earthquakes beyond those which the plant has been designed to accommodate. At some PWRs (such as Sizewell B) accidental aircraft impact has also been considered as a potential external hazard. The predicted accidental frequency is calculated from available crash statistics in the local area. For example, at the time of the Sizewell B public inquiry, the probability of an accidental military aircraft crash was estimated to be 1 in 2.5 million per year.[136]

In the event of a loss of coolant, the likely sequence of events at a gas-cooled reactor would be very different from that at a PWR, as described in Box 8-2.

Examples of accidents at nuclear reactors

It is important to note that two of the three most significant nuclear reactor accidents that have occurred in the history of nuclear power, Windscale and Chernobyl, involved reactor designs and operational practices that are not used in the UK today (see Box 8-1). The large release at Windscale was mainly because the reactor was air-cooled with the air being roughly filtered and then released into the atmosphere. The large release at Chernobyl was primarily due to the unsafe operating practices and inherent instability of the reactor design. In addition there was no proper containment around the reactor core, as a result of which large fragments of it were deposited in and around the reactor building in the course of the accident.

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[136] Report by Sir Frank Layfield, Sizewell B Public Inquiry, 1987 (Chapter 26, Section C (Aircraft Crash)).

Box 8-3 Examples of accidents at nuclear reactors

There have been two major accidents at civilian nuclear power plants to date: the Chernobyl accident in 1985 and the Three Mile Island accident in 1979, classed as level 7 ('Major accident') and level 5 ('Accident with off-site risk') on the International Nuclear Event Scale (see Annex 6) respectively. These are discussed below, along with a description of the fire at the Windscale military reactor in the UK in 1957.

Chernobyl, Ukraine[137]
The world's most serious civil nuclear power plant accident occurred in 1986 at the Russian designed RBMK reactor at Chernobyl. An experiment to test the passive safety features of the design went badly wrong due to a combination of the inherent instability of the reactor physics and the fact that it had been operating at low power for a long period before the test. Violations of safety procedures by the operators, including over-riding the control rod withdrawal stops, resulted in an uncontrolled power surge and explosion of the steam system. The destruction of the reactor building and the subsequent fire led to significant releases of activity to the environment. There are no reactors of this type in western Europe and those still operating in the Former USSR have been modified to remove the inherent instability. The consequences of Chernobyl are discussed in section 8.10.

Three Mile Island, Pennsylvania, USA
In March 1979, a malfunction occurred in the secondary cooling system of the unit 2 pressurised water reactor at Three Mile Island in the USA. This should not have had serious consequences, but the situation was exacerbated by a valve being stuck open, unnoticed by the operators, leading to loss of pressure in the primary coolant circuit. The water in the reactor vessel ended up 30 cm below the core and overheating occurred. Fuel temperature rose to above 2000 degrees Celsius in the reactor core, damaging 70% of the fuel and causing over one third to melt. A large hydrogen bubble formed in the pressure vessel, raising concerns over explosions leading to possible breach of containment.[138] Ultimately the reactor containment remained intact and the main release of radioactivity was via the primary coolant circuit. Most of the radioactivity escaping from the containment was in the form of noble gases (krypton and xenon) with only a small fraction of iodine escaping into the environment. An inquiry into the incident attributed it to a combination of faults including operator error, control room design and the safety culture of US nuclear industry at the time.[139]

Windscale, Cumbria, UK
On October 9th 1957, a fire started in an air-cooled graphite-moderated military reactor at Windscale. The fire quickly spread and burnt for 4 days before it was extinguished. The Windscale reactor was one of the earliest reactor designs. It had no containment and the coolant system was not closed – air was directly released to the atmosphere (although there were filters, these were not sufficient to contain the release). Thus a significant fraction of the inventory of several radioisotopes – core materials as well as materials surrounding the core - which were being irradiated at the time of the accident, escaped into the environment. Radioactive materials (with iodine-131 being the dominant component of ground deposits) were dispersed over England, Wales, and parts of northern Europe.

8.7 Terrorist attacks at nuclear reactors

There are three main sources of radioactive material at a reactor site from which terrorists might attempt to bring about a release of radioactive material:

- the reactor itself.
- the spent fuel cooling ponds.
- the radioactive waste storage facilities.

This section focuses on releases from the reactor itself. Spent fuel cooling ponds are discussed in section 8.11.[140] Terrorists might attempt to bring about a release from the reactor in two ways:

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[137] www.world-nuclear.org/info/inf36.htm ; www.unscear.org/pdffiles/1988annexd.pdf

[138] http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html

[139] Report by the International Nuclear Safety Advisory Group. *Radionuclide source terms for severe accidents to nuclear power plants with light water reactors*, IAEA, 1987.

[140] Radioactive waste at reactor sites is not discussed further in this report, because in comparison to the reactor itself or the spent fuel cooling ponds, the quantities of radioactivity involved are small and moreover the waste does not generate heat.

- directly - as reactor cores are protected by thick concrete shielding, breaching the reactor containment and shielding would require a violent impact or explosion.
- Indirectly - equipment outside the reactor building (e.g. generators) might sustain more damage than the reactor core itself, as it is in buildings which do not have the same degree of shielding.

Studies in the public domain

The sequence of events that might be brought about by a terrorist attack could be broadly similar to those that might occur as a result of an accident. Thus, to understand whether a nuclear power reactor could withstand a given form of terrorist attack, one would need to establish whether the physical damage resulting from the attack would fall within the design basis – i.e. within the envelope of fault sequences that the reactor is already designed to handle. This requires detailed structural analysis of the potential damage resulting from a range of potential terrorist acts.

Much of the work done to assess the vulnerability of nuclear reactors over the past three years is not publicly available. Internationally, the IAEA has carried out assessments of the physical robustness of nuclear facilities, including power plants, against both deliberate and accidental events,[141] and was involved in a number of aircraft crash analyses in conjunction with specific member states, which are largely not in the public domain. In the UK, the nuclear industry has carried out vulnerability assessments, in collaboration with government and regulators. These results are also not publicly available. It is, however, known that the studies not only took into account the physical robustness of the reactors themselves, but the robustness of security regimes, and their effectiveness in preventing an attack being mounted in the first place.[142]

However, there is some public information available, from NGOs as well as from a number of overseas operators and regulators, Below, published commentary relevant to the threat of aircraft impact, maritime attacks, vehicle bombs and truck bomb attacks is discussed. Aircraft impact is discussed in more detail here, because there is more public commentary on aircraft impact than on other modes of assault.

Aircraft impact

Although some commercial reactors such as Sizewell B, have been designed to withstand the accidental impact of light aircraft, no reactors have been designed specifically to withstand the impact of a large commercial aircraft, as this was not a conceivable threat at the time of their design. Assuming that a terrorist group could overcome security and succeed in targeting the reactor building, structural damage could be caused not only by the impact of the aircraft itself, but also as a result of the blast and fire from burning aviation fuel, and by parts of the aircraft acting as projectiles (see Box 5-1**).** The consequences would also depend on the reactor design.

Box 8-4 discusses analyses conducted by various overseas nuclear operators and regulators on the vulnerability of nuclear power reactors to aircraft attack. Conclusions vary depending on design and on the type of aircraft used in the analyses, and the speeds assumed. Some studies, such as the US NEI study, rule out the possibility of breaches of reactor containment at the

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[141] This work has been carried out as an extension of the IAEA's existing research programme: "The Safety of Nuclear installations in Relation to Human Induced Events" which considers human induced events of accidental origin (e.g. pipeline explosions, airplane crashes, toxic/flammable gas intrusions, fires, internal flooding.). The IAEA have issued a number of guidance documents relating to such events.

[142] Note that the NII, the nuclear safety regulator, is not currently undertaking any studies of structural response as it states that current understanding is "relatively well refined", although it is monitoring international work in this area. The NII also states that the licensees are undertaking their own, desk top, assessments.

speeds analysed, while others, such as the studies of German reactors, conclude that newer plants are much less vulnerable than older plants, but that the risk of radiological release cannot be ruled out in either case. These examples cannot be directly compared with one another, or used to draw conclusions about UK nuclear power reactors, because reactor designs vary in different countries (for example there are design differences between the Sizewell B PWR in the UK, and US PWRs). Due to design characteristics, older PWRs may be more likely to sustain physical damage in the event of a terrorist attack than more recently designed PWRs.[143]

UK nuclear power plants

There are no publicly available studies of large aircraft impact on UK nuclear power plants. Studies of the impact of a *military* aircraft on the Sizewell B reactor[144] carried out in the 1980s indicated that in the highly unlikely event of an accidental impact, there was a 3 to 4 % probability of uncontrolled release of radioactive material. The annual frequency of an uncontrolled release resulting from *accidental* aircraft impact was then evaluated at 1 in 50 million. However this figure is not relevant in the event of a deliberate attack.

French nuclear power plants

Studies carried out over the past three years by Electricité de France (EDF), the French nuclear operator, as well as by the French Safety Authority, are classified and no public report is planned. However, according to EDF, they indicate that *PWR containments are robust structures that would resist a large range of commercial aircraft impact scenarios (in terms of speeds and angles).*

Aircraft impact on gas-cooled reactors

Most commentary in the public domain focuses on Light Water Reactors (LWRs). There is very little on terrorist attacks on gas-cooled reactors, largely because the UK is the only country where this design is prevalent. Some of UK's older Magnox plants have design characteristics which may make them more vulnerable to terrorist attack. However, POST has been requested not to discuss these, to avoid highlighting sensitive information which might be of use to terrorists, although some of the information is already in the public domain.

Comparing the vulnerabilities of pressurised and gas-cooled reactors

More detailed studies would be needed to draw general conclusions on the relative vulnerabilities of gas-cooled versus pressurised water reactors. At first glance it would appear that gas-cooled reactors might be more likely to sustain physical damage in the event of an aircraft impact, because they are not housed in external containment buildings – the only protection surrounding the reactor core is the concrete pressure vessel/biological shield, which is not fully hermetic, and the reactor building, which is a normal industrial building and not comparable with a PWR containment. However, without detailed structural analyses it is difficult to predict what would happen. Many other factors would also need to be considered – for example the fact that the core of a gas-cooled reactor would heat up more slowly than a PWR core after a loss of cooling (see previous section) thus allowing more time for remedial action to be taken.

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[143] Although POST originally planned to discuss these design issues in more detail, POST has been requested to omit this detail, to avoid highlighting sensitive information which might be of use to terrorists, even though some of this information is already in the public domain.

[144] Report by Sir Frank Layfield, Sizewell B Public Inquiry, 1987 (Chapter 26, Section C (Aircraft Crash)).

Box 8-4 Overseas studies on the vulnerability of nuclear power plants to aircraft attack

Below, some of the conclusions drawn by overseas nuclear operators and regulators are discussed. There is wide variation in the level of detail available for different countries, although none of the publicly available reports contain full detail of the analyses for security reasons.

US Nuclear Energy Institute (NEI)[145]
Studies commissioned by the NEI in 2002 involved simulating aircraft impact on various structures that directly house nuclear fuel (including US reactor buildings, US spent fuel cooling ponds and US fuel shipping containers). The study concluded that none of the structures considered would be breached at the analysed speeds (156 m/s or 560 km/h) by a commercial aircraft such as a Boeing 767. The speeds used were based on analyses of the crash of the aircraft hijacked on September 11th 2001 into the Pentagon building and discussions with experienced pilots. High speed impacts were ruled out *on the basis of controlling a large commercial aircraft close to the ground*, although the study points out a number of conservatisms that provide substantial margin even if higher speeds were used. Other analysts have criticised this analysis as being *highly constrained in terms of the range of aircraft speeds and angles used.*[146] The study did not consider the effects of an aviation fuel fire as it was assumed that it would not enter any of the structures that house nuclear fuel. The NEI emphasised the fact that nuclear installations are small targets compared with the World Trade Centre in New York, USA and the Pentagon buildings in Washington DC, USA.

Swiss Federal Nuclear Safety Inspectorate (HSK)[147]
HSK has carried out analyses the consequences of various types of aircraft impact, ranging from small propeller aircraft to large commercial aircraft (e.g. Boeing 747) on its power plants. For the two older plants, Beznau (2 PWRs) and Mühleberg (BWR), the report concluded that for higher speed impacts, the possibility of penetration of the reactor building, resulting in damage to safety equipment and systems *could not be ruled out* ; the extent of the damage would depend on the consequences of fire within the building. The report also concluded that other buildings containing emergency systems were adequately protected against fire and debris, but that smoke might affect the performance of some emergency equipment outside the reactor building. In both cases, accurately targeting the reactor building would be very difficult because of either site location or site layout. For the two most recently constructed plants, Leibstadt (BWR) and Gösgen (PWR), the report rules out the possibility of penetration of the reactor building, constructed in the late 1970s and early 1980s. These plants were designed to withstand the impact of a Boeing 707 travelling at 370 km/h but the analyses show that they could withstand the impact of larger aircraft travelling at higher speeds.

German authorities
Studies commissioned by the German government conclude that older plants are more at risk than newer plants, primarily due to differences in the strengths of the containment structures, but that the possibility of a large aircraft crash on a newer plant resulting in a release could not be ruled out. [148] A summary of a report produced for the German Federal Ministry of the Environment describes how analyses were carried out using a range of different aircraft and speeds: the maximum speed for large aircraft was assumed to be 175 m/s (630 km/h) and 215 m/s (775 km/h) for smaller aircraft (based on analyses of the World Trade Centre attacks). The study looked at a range of German PWR and BWR plants. The vulnerability of the plants studied was found to vary considerably. Overall, the study concluded that Germany's BWRs were more vulnerable than its PWRs. For some types of BWR, the possibility of release, either from the reactor building or the spent fuel ponds, could not be ruled out, for a range of different types of aircraft. In all cases the study concluded that unless there were direct damage to these buildings or to the reactor control room (rather than other 'safety relevant buildings') , the situation would be controllable. After this report was leaked there has been renewed debate over the future of Germany's older BWRs, and over how to classify the risk from aircraft impact.[149]

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[145] Nuclear Energy Institute, *Aircraft Impact Analyses Demonstrate Nuclear Power Plants' Structural Strength,* summary of a report produced by the Electricity Power Research institute (EPRI) at the request of the NEI. This study was independently peer reviewed by two consulting engineering firms. but full details of the study cannot be released to the public for security reasons.

[146] Alvarez et al., *Reducing the Hazards from Stored Spent Power Reactor Fuel in the United States,* 2003.

[147] Hauptabteilung fur die Sicherheit der Kernanlagen, *Position of the Swiss Federal Nuclear Safety Inspectorate regarding the Safety of Swiss Nuclear Power Plants in the Event of Intentional Aircraft Crash,* March 2003.

[148] Reaktor Sicherheits Kommission, *Safety of German nuclear power plants to withstand deliberate crash of a large, fully fuelled aircraft.* October 2001. www.rskonline.de/stellungnahmen/SN-AbsturzGroßflugzeugen_11_10_01.pdf

[149] Federal Ministry of the Environment, Nature Conservation and Nuclear Safety, *Protection of German Nuclear Power Plants against the Background of the Terrorist attacks in the USA on September 11th*. This is a classified summary of a report produced by consultancy firm Gesellschaft für Anlagen- und Reaktorsicherheit mbH (GRS), which was leaked to the media in late 2003.

Options to increase robustness of nuclear reactors

It is not feasible to retrofit existing power plants to withstand attacks such as large aircraft impact, but several options are being considered to minimise the impact of such attacks. In general, the measures which are being investigated by different countries, including the UK, are not publicly discussed, for security reasons. The possibility of constructing anti-aircraft barriers around some installations has been considered, for example:

- The US Nuclear Energy Institute looked into the feasibility of installing aircraft shields of various types to intercept aircraft, but concluded that *the costs of these shields are prohibitively expensive and have not been pursued because they would have to be seismically qualified and meet hurricane wind loadings.*[150]
- The German Environment Ministry investigated the feasibility of a proposal to install 'fog shields' at nuclear plants which would create a wall of artificial fog within seconds to disguise a target in the event of a terrorist attack.[151] However a recent press report (cited in the absence of other published information) suggests that such measures might be less effective than originally supposed, because even an indirect hit by a large jet could in some cases, and at certain reactors, result in a serious accident, and the presence of a dense fog would be likely to hamper recovery efforts on the ground.[152]

Some measures are also being taken to increase the robustness of research reactors (section 8.8) - for example there are plans to construct a 'metallic grillage' around parts of the ANSTO research reactor currently under construction in Australia.[153] This can be seen on the artist's impression in Figure 8-3. It will provide an extra layer of protection against light aircraft impact in addition to the protective concrete layer around the reactor core.[154]

In the case of PWRs, the risk of internal explosions[155] at existing plants can be reduced by installing 'hydrogen recombiners' which prevent hydrogen from building up within the reactor pressure vessel. This has been done at all Belgian nuclear power plants and work is underway at French nuclear power plants (Sizewell B already has hydrogen recombiners).

Finland is the only country in Europe where there are definite plans for new reactor build. Finnish regulations now require the impact of large passenger or military aircraft to be taken into account at the design stage, although further details are not available.

Vehicle bombs

There is little analysis in the public domain about the consequences of a vehicle bomb attack on UK reactors. The only detailed study on truck bomb attacks whose results are in the public domain was carried out almost 20 years ago by Sandia National Laboratory in the USA, at the request of US Nuclear Regulatory Commission. This concluded that a truck bomb attack could cause '*unacceptable damage to vital reactor components*' even if the truck bomb were detonated off-site.[156] Any subsequent studies have not been made publicly available. As

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[150] Personal communication from Nuclear Energy Institute to POST, August 2003.

[151] Germany Environment Ministry, *Atomkraft: Gefahr von Angriffen vermindern*: Statement issued on December 2003 .

[152] Nucleonics Week, January 22nd 2004.

[153] Australian Nuclear Science and Technology Organisation.

[154] *Summary of the Preliminary Safety Analysis Report for the ANSTO Replacement Reactor Research Facility,* vol. 1 section 4.4.1.2.2, May 2001.

[155] Internal explosions can occur at pressurised water reactors as a result of build-up of hydrogen gas following loss of coolant.

[156] As quoted in reference 65.

mentioned in Chapter 6, UK nuclear sites take measures to restrict and control vehicle access, such as installation of chicanes, and searching of vehicles[157].

Figure 8-3 Artists impression of the ANSTO Replacement Research Reactor

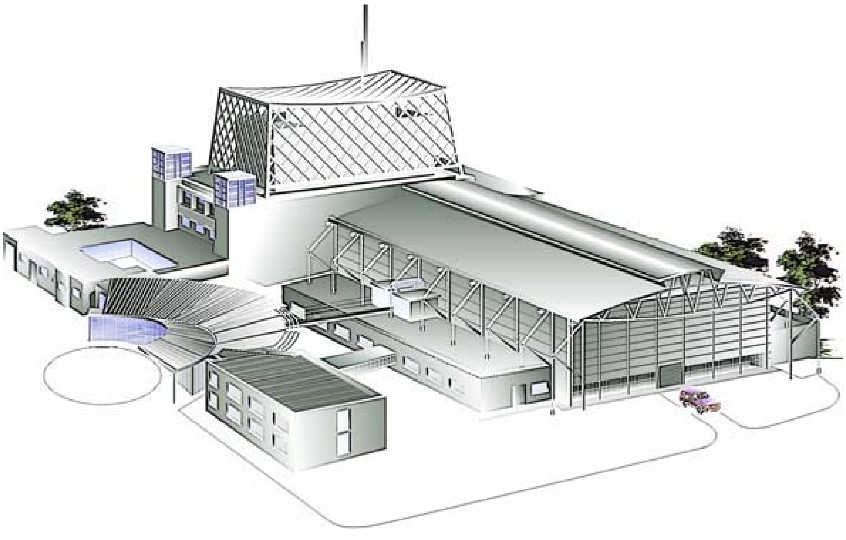

Image reproduced courtesy of ANSTO.

Ground-based attack

A ground-based attack (e.g. by armed intruders or by insiders) might be carried out with a view to either physically damaging vital parts of the plant or gaining access to the plant controls. Such attacks would first have to overcome security guards and physical security barriers to reach the vital areas of the plant (as defined in Box 3-2). Assuming that terrorists did overcome security, it is difficult to predict the extent of the damage that could be inflicted as this depends on the number of intruders, the kind of arms they could carry, and the degree of insider assistance. In terms of physical effect, as a result of redundancy in reactor design, damage to one individual system should not lead to a release of radioactivity, as mentioned earlier. Although modern plants in the UK such as Sizewell B have a greater degree of redundancy than older reactors, all employ a degree of redundancy. A ground-based attack would therefore need to be highly co-ordinated and would require detailed site specific knowledge of plant operations and design.

OCNS and NII initiated a project to guard against unauthorised interference with safety-critical IT systems in 2001, although a recent OCNS report stated that no progress had been made in the past year, due to other priorities.[158] British Energy state that even if intruders gained access to a plant control room, '*its reactors are designed such that it is not possible to override safety systems and to intentionally disable enough critical systems to cause a large release*'.

Attacks using Liquid Natural Gas or Liquefied Petroleum Gas tanker ships

Some analysts suggest that there is a threat from terrorist attacks on Liquefied Natural Gas (LNG) or Liquefied Petroleum Gas LPG or tanker ships passing coastal facilities. Two main terrorist attack scenarios have been postulated:

- A terrorist attack on a tanker, leading to an explosion, the blast from which would cause structural damage to a facility

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[157] Note that British Energy claim on the basis of internal studies, '*a truck bomb would not cause unrecoverable damage to vital reactor components, even if detonated on-site*'.

[158] Office for Civil Nuclear Security, *The State of Security in the Civil Nuclear Industry,* April 2003- March 2004.

- A terrorist attack leading to release of a cloud of inflammable gas, which could then explode as it passed over the nuclear facility.

There is very little public commentary on these scenarios, but studies have been carried out by the CEGB for the Sizewell B public inquiry[159], and also by Electricité de France prior to the construction of the Gravelines power plant. In both cases, the main risk identified was the latter- i.e. a cloud of gas exploding over a nuclear facility, rather than a tanker explosion.[160] In the case of Sizewell B, the probability of an *accidental* uncontrolled release of radioactive material was considered too low to necessitate consideration in the design of the plant. However, one cannot draw conclusions from this about the probability of a *deliberate* release resulting in serious damage.

Some analysts argue that the threat has been underestimated. In a recent talk given to the Nuclear Free Local Authorities (NFLA),[161] it was argued that the potential for catastrophic consequences arising from such an event is a matter of concern even if the likelihood of the event might be small.[162] However there is considerable uncertainty involved in predicting what fraction of the contents of such tanker ships would be likely to explode in the event of an attack – it was pointed out that '*it seems technically impossible to predict how much of that potential would effectively explode and how much would burn off in a gigantic fire*'.[163] Nevertheless it was argued that liquefied gas tanker ships, which typically carry 130,000 cubic metres of LNG, frequently pass through the harbour at Cap de la Hague and that '*even a 1% efficiency or less would lead to unbearable consequences in the vicinity of a plant like La Hague or Sellafield*'.[164]

Other analysts, however, argue that the main hazard presented by terrorist attack is fire, not detonation, as ignition of LNG can take place only under very specific conditions. They also argue that danger to the public would be minimised by the separation distance of the facility.[165]

Other modes of attack

Some analysts have even considered the possibility of attacks on nuclear reactors using conventional weapons.[166] Such analyses relate to attacks as acts of war as well as terrorist incidents. A press release issued by Greenpeace in 1996, based on a report produced by the Institute for Resource and Security Studies (IRSS), stated that '*a non-nuclear attack on a nuclear reactor could lead to a complete range of releases, depending on whether core meltdown took place and how severely the containment was damaged*'.

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[159] Prior to the privatisation of the UK electicity industry in 1990, most electricity was generated by the Central Electricity Generating Board (CEGB), a government owned nationalised industry which also operated the national grid transmission system.

[160] As it was considered that at a distance of a few hundred metres, the tanker would be too far away to inflict severe damage.

[161] 81 local governments are members of Nuclear Free Local Authorities (NFLA), which campaigns against commercial nuclear power and military nuclear activities. The mission statement of the NFLA steering committee is to '*work for a nuclear free future in practical ways within local government*'.

[162] Presentation given by Mycle Schneider at the 5th Irish & UK Local Authorities Standing Conference on Nuclear Hazards, March 2003, Cork, Ireland. Mycle Schneider is an independent analyst on energy and nuclear policy and former Director of WISE-Paris.

[163] See 162

[164] See 162

[165] Institute for Energy, Law and Enterprise, University of Houston, *LNG Safety & Security*, October 2003.

[166] G. Thompson, Institute for Resource and Security Studies, *War and Nuclear Power Plants,* March 1996. http://www.antenna.nl/~wise/terrorism/031996war.html

8.8 Research reactors

Background

Research and test reactors have both civilian and military applications. As of March 2004, there were 284 civilian research reactors in operation in 56 countries. Research reactors are much smaller than power reactors – a typical design contains a few kg of fuel compared with over a hundred tonnes in a typical power plant. There is a wide range of different designs. A common approach is to place fuel elements in a tank or pool of water which acts as both moderator and coolant. Other designs use heavy water or graphite as a moderator. Some research reactors are fast reactors (see Box 8-1) and do not require a moderator.

There has been some speculation in the public domain over the potential terrorist threat to research reactors, relating both to the threat of sabotage, and to theft of material.

Sabotage of a research reactor

The consequences of sabotage of a research reactor would not be comparable with a power plant in terms of the radioactivity released into the environment, because of the huge differences in the amounts of fuel involved.

Nevertheless a recent paper by the Institute for International Studies at Stanford University pointed out that research reactors are not as well protected (both physically and in their security regimes) as power plants and therefore might still make attractive targets.[167] The authors suggest that attacks involving a vehicle crash and subsequent explosion might lead to dispersal of radioactive material and argue that *nuclear regulators should reassess the level of physical protection that research reactor operators provide in the light of the increased terrorist threat.* However the paper also emphasised that there were wide variations in security and in the physical robustness of research reactors worldwide, with those in the West generally being better defended against terrorist activities. The authors do not consider reactors with power outputs of 100 kW or less in their study, because of their low radioactive inventory. The UK's only remaining civilian research reactor at Silwood Park in Berkshire (see Box 8-5) falls below this threshold. Nevertheless, concerns have been raised by local groups about the operation the reactor.

Theft of material

Many research reactors use highly enriched uranium (HEU) as fuel, which could potentially be used to construct crude nuclear weapons as well as 'dirty bombs'.[168] There are various initiatives to convert research reactors to using low enriched uranium, such as the Reduced Enrichment for Research and Test Reactors (RERTR) programme, launched by the USA in 1978. To date, this programme has converted or is converting over 40 research reactors in the USA and abroad to using LEU fuel. Although using LEU reduces the proliferation risk, the environmental and health implications of sabotage would be comparable whether the fuel were HEU or LEU.

International programmes

The IAEA has a work programme focussing on the safety of research reactors. This involves assisting member states to evaluate the vulnerability of their sites as well as improving emergency preparedness. The focus of the IAEA's work is on-site considerations, as the agency argues that for small reactors (which it defines as less than 40 MW), the likelihood of off-site radiological consequences in the case of an extreme accident is *'very low'*.

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[167] Bunn et al., *Research Reactor Vulnerability to Sabotage by Terrorists,* Institute for International Studies, Stanford University, 2003. http://iis-db.stanford.edu/listpubs_fac.lhtml?fid=2037&cntr=cisac

[168] G. Bunn and C.Braun, '*Terrorism Potential for Research Reactors Compared with Power Reactors',* Centre for International Security and Co-operation, Stanford University, 2003.

Box 8-5 Silwood Park research reactor

Silwood Park research reactor is run by Imperial College, University of London and is located on the Silwood Park research site near Ascot in Berkshire. It is now the only civilian research reactor in the UK and is used widely by both industry and academia, including for teaching purposes.

Operations
The nuclear site itself consists of the research building within which the reactor is housed and its immediate vicinity. The core of the reactor, which is only ~60cm high, contains fuel in the form of uranium metal in aluminium cladding, surrounded by water which acts as both moderator and coolant (circulating naturally by convection). As with a power plant, the rate of the reaction can be controlled with control rods that are lowered into the reactor from above.

Safety
Safety measures at research reactors are less stringent than at power plants, reflecting their smaller radioactive inventories. Moreover, the temperatures at which this reactor operates are much lower (the average core temperature is only 40 degrees Celsius). Nevertheless, some safety upgrades are under way, such as the addition of an emergency shutdown system. According to the site safety case, there are no foreseeable accidents which could result in off-site release of radiation from this reactor. Contingency planning arrangements are therefore limited to dealing with an on-site release of radiation.

Security measures at Silwood Park
Security is regulated by OCNS. Measures are less stringent than at a power plant, reflecting the lower hazard potential of the site. According to OCNS, these measures '*are still assessed as comprehensive and effective commensurate with the risks and consequences of a terrorist attack*'.

8.9 Consequences of a release from a nuclear reactor

As explained in Chapter 7, the consequences of a release from any nuclear facility depend on the nature of the release itself (i.e. the type and quantity of radioactive material) as well as subsequent environmental factors and emergency measures taken to protect the public. Specific characteristics of a release from a nuclear reactor are discussed below. Two case studies are then provided to illustrate the potential consequences of a release from a nuclear reactor: hypothetical studies carried out in the 1980s for the Sizewell B public inquiry, and actual data on the consequences of the Chernobyl accident.

Characteristics of release

The principal source of radioactivity in a nuclear reactor is the spent, or irradiated, fuel.[169] This is mostly made up of uranium but also contains a few percent of plutonium, other actinides and radioactive fission products.[170] The radionuclides in the fuel can be divided into the following categories according to how easily they can be released:

- gaseous: this includes noble gases (e.g. xenon and krypton) as well as gaseous iodine.
- volatile: this includes materials such as iodine, caesium and tellurium. These materials can attach themselves to aerosol particles and escape into the atmosphere.
- non volatile: materials which will not vaporise and so are less easily dispersed, such as plutonium. Non volatile materials are generally released as heavier particles several microns (1 micron = 1 millionth of a metre) in diameter.

The amount of material released depends on a number of factors, as outlined in Box 8-6. Also, the mobility of these elements and their quantities will determine their environmental and health impacts. For example, iodine-131 and caesium-137 are important radionuclides because they are readily released and move easily within the environment.

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[169] Although the surrounding materials also become radioactive as a result of contamination and neutron bombardment.
[170] See glossary for definition of actinides.

Box 8-6 Fission product dispersal

The radioactive inventory of a reactor varies depending on factors such as the type of reactor and the stage of the fuel in its cycle. Fresh fuel will contain fewer radioactive fission products than fuel nearing the end of its lifetime. In the event of either a terrorist attack or of an accident, it cannot be assumed that the entire radioactive inventory will be released into the environment, as some part of it will be retained within the reactor. The amount released depends on a number of factors, described below:

- the extent of the damage - in the worst-case scenario, if the pressure vessel were breached, radioactive material could be released into the atmosphere as with Chernobyl. Even were the pressure vessel not breached, radioactive material might still escape via the coolant system. The nature of the release would then depend on the interactions taking place between the fission products and the coolant.
- Temperature - the higher the temperatures in the reactor core, the more fission products will be released from the fuel elements. In an extreme scenario fires within a reactor core (e.g. within the graphite moderator of a gas-cooled reactor) could increase dispersion of radioactive material.
- chemical conditions - the chemical form of the fission products will determine the extent to which they are retained within the reactor. For example, it is thought that the reason why relatively little iodine escaped from the Three Mile Island reactor is because chemical conditions favoured formation of metallic soluble iodides that dissolved in water. However at Windscale, the iodine remained in gaseous form and almost 10% of the total inventory was released.

The consequences of a release from a nuclear reactor would differ from facilities where spent fuel is housed (see 8.11). An operational reactor would have a substantial inventory of short-lived isotopes such as iodine-131, whereas in irradiated fuel that had been removed from a reactor some time ago, the longer-lived isotopes would be more important. Also, there would be more heat available in the core of a nuclear reactor to mobilise and disperse the radioactive inventory.

Source terms

Computer-based models can predict the source term (size and nature of a release) for different scenarios. This can then be input into further models which determine the path of radioactive material through the environment. There is a great deal of uncertainty involved in predicting the size of the source term, as the exact course of events cannot be known. Many of the processes occurring, such as transport of fission products through the coolant, or circulation of fission products within a reactor vessel, are very difficult to model.

8.10 Case studies

Modelling studies – Sizewell B

Modelling studies on the consequences of nuclear *accidents* at the Sizewell B plant were carried out to inform the public inquiry (1984-1987).[171] Analyses were conducted by the Central Electricity Generating Board (CEGB), who were presenting the case for constructing the plant and also by the NRPB and various interest groups. Some results are discussed here to provide a broad indication of the consequences of various sequences of events, which might occur as a result of either a terrorist attack or an accident. Note, however, that many of the input data and assumptions used by these modelling studies have changed since the time of the study, for example population density, information on emergency planning arrangements, and assumptions on the link between radiation doses and cancer risk. In addition, for a given sequence of events, the consequences were shown to vary widely depending on weather conditions.

Design basis scenarios[172]

The CEGB showed that for some design basis scenarios, bans on milk would be necessary to limit doses to the thyroid.[173] [174] In addition, some scenarios would require a ban on local crops.

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[171] Similar analysis are available for the proposed Hinkley point PWR. However there are no published analyses for gas-cooled reactors in the UK.

[172] Report by Sir Frank Layfield, Sizewell B Public Inquiry, 1987 (Chapter 33 Section C).

These bans would need to be imposed over an area of the order of 10-20 km^2 depending on the weather and the time of year. However, the CEGB concluded that no design basis scenario would require evacuation or sheltering of a member of the public, or issue of iodine tablets. The most severe health consequences predicted to arise from a design basis scenario were roughly four extra fatal cancer cases and fifty non-fatal cases in the whole of the UK, and six times these numbers in the rest of Europe.

Beyond design basis scenarios

The NRPB investigated the consequences of twelve different beyond design basis release scenarios involving damage to the reactor core.[175] Wide variation in consequences arose from many factors such as the duration and size of the release, the height of the radioactive plume, weather patterns, and whether there was any warning time. Some of the key results were:

- The health effects predicted to affect the greatest number of people were fatal cancers and hereditary effects. The expectation value[176] for fatal cancers varied from only one or two, for the smaller releases, to over one thousand for the larger releases.
- In several scenarios there were short term deaths from acute radiation exposure, but expectation values of less than 10 such deaths were predicted even for larger releases.
- For the larger releases, evacuation might be necessary over a mean area of 20-30 km^2 and the expectation value for the numbers of people evacuated could exceed 3,000.
- Crop restrictions might be necessary over an expected area of over 1,000 km^2 for the larger release scenarios. Bans on several million litres of milk might also be necessary. The UK consumed about 40 million litres of milk a day at the time of the study.

Some interest groups raised concerns over the potential consequences of extreme situations, for example, the most severe accident sequence combined with the most adverse weather patterns. The Greater London Authority argued that certain extreme scenarios might even affect large parts of London. In all cases, the numbers of people and areas of land affected by countermeasures would depend on the dose thresholds used for their implementation, which would have to take into account logistical limitations to implementation over a wide area, particularly for countermeasures such as evacuation.

Data from the Chernobyl accident

The Chernobyl accident cannot be used to draw direct inferences about the potential consequences of a release of radioactive material from a modern reactor, as it was largely the result of flawed reactor design and operational procedures which are not in use in the UK or any other country in Western Europe. However, since it is the most severe accident at a civil nuclear facility to date, it is discussed here to provide a broad indication of the consequences of such an incident.

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[173] The CEGB made conservative estimates of the radiation dose received by members of the public, based on the dose that would be received by a one year old child at the site fence.

[174] In the absence of restrictions on milk consumption, doses were predicted to reach several thousand mSv for some of the larger releases, exceeding the lower ERL of 300 mSv for evacuation for exposure of the thyroid.

[175] National Radiological Protection Board, *An Assessment of the Radiological Consequences of Releases from Degraded Core Accidents for the Sizewell PWR,* NRPB-R137, July 1982. Note that the mean figures cited for the larger releases are from taken from revised versions of the original calculations, which were thought to have been overestimated. Revised calculations for the smaller releases are not available.

[176] The expectation value is the theoretical mean value of a random variable (e.g. number of fatal cancers; numbers of people evacuated).

Size and nature of release[177]

A significant fraction of the reactor's radioactive inventory was released into the atmosphere - half the iodine inventory as well as almost a third of of the caesium inventory,[178] and about six tonnes of fragmented fuel (~3.5% of the total core inventory). The radioactive material released ranged from gases and aerosols of less than 1 micron in diameter, to much heavier particles, which were mostly fine fragments of fuel from the reactor core itself. These heavier particles were found mostly within a 100 km radius of the reactor, but the lighter particles were carried much greater distances and led to increased levels of radioactivity throughout Europe. Two factors contributed to widespread contamination: Firstly, the release lasted over ten days, during which time wind directions varied considerably, carrying the radioactive material in many different directions. Secondly, the heat associated with the release (from explosions and fire) meant that the radioactive plume was over two kilometres high.[179]

Areas affected within the Former Soviet Union (FSU)

The highest levels of radioactivity were measured in the 30 km area surrounding the reactor, from which 161,000 people had to be evacuated. Outside this zone, the most seriously affected areas were parts of Russia, the Ukraine and Belarus. About 370,000 people from these areas have now been resettled.[180] Many found it difficult to adapt and continue to face economic, social and psychological problems.[181] According to UNSCEAR, around 150,000 km^2 of land (the combined area of England and Wales) was still defined as contaminated in the year 2000.[182] In other areas, various measures are being taken to reduce the dose received from local produce. About 4.5 million people continue to live in these zones.[183] The restrictions in force in these areas depend on the level of radioactivity. Almost 15,000 km^2 of agricultural land and forest in Belarus and the Ukraine have been removed from service.[184]

Areas affected outside the FSU

According to UNSCEAR, the worst affected areas outside the FSU were the Scandinavian countries, as well as Austria and Bulgaria – although levels of radioactivity were high enough to warrant countermeasures (mostly food related) in most European countries, including the UK.[185] About 45,000 km^2 outside the FSU are contaminated with caesium-137[186], with localised 'hotspots' of radioactivity occurring where showers fell as the plume was passing overhead. In the UK, some restrictions are still in place - as of April 2004, a total of 382 farms (359 in Wales, 14 in Scotland and 9 in England) with some 221,500 sheep were still under restriction orders.[187]

Economic costs

The economic impacts of Chernobyl were most severe in Russia, Belarus and the Ukraine. It is difficult to estimate the scale of the economic losses accurately at national level because different

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[177] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), *Exposures and effects of the Chernobyl accident*, 2000. (para 22 and 58).

[178] Based on figures for the amounts of I-131 and Cs-137 released compared to the estimated inventories in the reactor at the time of the accident.

[179] In general, the higher the plume, the more widespread the contamination.

[180] http://www.world-nuclear.org/info/chernobyl/inf07.htm

[181] UNDP/UNICEF report, *The Human Consequences of the Chernobyl Accident*, January 2002, http://www.undp.org/dpa/publications/chernobyl.pdf.

[182] In this instance contamination is defined as over 1 curie of radioactivity (37 billion Becquerel) from caesium-137 per km^2. Contamination is expressed in terms of caesium-137 deposition because it is easily measured and has been a major contributer to the long term radiation dose.

[183] UNDP/UNICEF report, *The Human Consequences of the Chernobyl Accident*, January 2002, (Table 2.2).

[184] UNDP/UNICEF report, *The Human Consequences of the Chernobyl Accident*, January 2002, (Table 5.2).

[185] See POSTnote 45 for information on the impacts of Chernobyl fallout on the UK.

[186] UNSCEAR, *Exposures and effects of the Chernobyl accident*, 2000. (para. 60).

[187] Source: Food Standards Agency.

methods are used in different countries. However, all countries suffered considerable losses, which can be categorised as follows[188].

- direct damage caused by the accident.
- expenditure related to managing the disaster, e.g. social protection and healthcare; resettlement of people and environmental monitoring.
- indirect losses, e.g. from loss of agricultural land and forests, and closure of agricultural and industrial facilities.
- energy related losses, e.g. the additional cost of energy due to the loss of the Chernobyl complex and the cancellation of Belarus's nuclear power programme.

The government of the Republic of Belarus estimate that the losses over the first 30 years following the accident will amount to $235 billion. Chernobyl-related expenses amounted to over 20% of Belarus's national budget in 1992 and were still over 5% in 2000. Analysts in the Ukraine estimate losses of ~$148 billion between 1986 and 2000.[189] The Russian state incurred costs of almost $4 billion between 1992 and 1998 alone as a result of Chernobyl (most of which was on compensation to those affected).[190]

Radiation doses received

The most important radionuclides in terms of the radiation dose received by the public, were iodine-131 and caesium-137. Iodine-131 was the main contributor in the first few weeks after the accident, with caesium-137 becoming more important later. Exposure to iodine-131 occurred through consumption of milk from animals which had eaten contaminated grass. Exposure to caesium-137 occurred (and is still occurring) largely as a result of its deposition in soil and subsequent uptake by plants which are eaten by people or livestock.

Health effects

Short term: Of the 444 workers on-site at the time of the Chernobyl accident, 134 received sufficiently high doses to suffer from severe radiation sickness and, of these, 28 died within the first three months. Three workers died for reasons not related to radiation exposure.

Long term: The most significant long term health effect, resulting directly from radiation exposure, is an increased incidence of thyroid cancer from exposure to iodine-131.[191] By 1994, the incidence of thyroid cancer in Gomel, which is immediately to the north of Chernobyl and under the path of the initial fallout cloud, was 100 fold greater than before the accident.[192] According to UNSCEAR, *about 1,800 cases of childhood thyroid cancer (mostly curable) occurred in Belarus, Ukraine and the Russian Federation in those who were children at the time of the accident.*[193] UNICEF/UNDP state that *a conservative estimate of the numbers of cases of thyroid cancer occurring over the lifetimes of those exposed in childhood is 6 to 8,000 in the three countries.*[194]

Note that a comparable increase in the incidence of thyroid cancer in the areas around Windscale most contaminated by iodine-131 has not been reported. This has been attributed to

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[188] UNDP/UNICEF report, *The Human Consequences of the Chernobyl Accident*, January 2002, (Box 5.1).

[189] UNDP/UNICEF report, *The Human Consequences of the Chernobyl Accident*, January 2002, (para. 5.04,Table 5.1).

[190] http://www.chernobyl.info/en/Facts/Consequences/OverviewStateEconomy

[191] Iodine-131 can be transferred rapidly to humans through the air, milk and leafy vegetables. The body accumulates iodine in the thyroid gland, which means that the radioactive dose is concentrated in a small area. This is likely to be the reason why iodine-131, unlike other radionuclides, is closely associated with a specific cancer.

[192] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), *Exposures and effects of the Chernobyl accident*, 2000. Para. 263 p 497.

[193] Out of a background population of 10.6 million. See http://www.unscear.org/press_releases.html

[194] UNDP/UNICEF report, *The Human Consequences of the Chernobyl Accident*, January 2002, para 4.17.

the prompt introduction of a ban on milk produced in the area, which reduced the exposure of those most at risk: infants and children. Other long term health effects from radiation exposure due to Chernobyl have not been established to date. However, a range of other effects has been suggested, such as a tendency for an increase in leukaemia in people working on-site in 1986 and 1987.[195]

Uncertainty in health impacts
There remains widespread controversy over the possible long-term health effects of the Chernobyl accident. Figures provided by many NGOs are significantly higher than those in official reports. According to the UNICEF/UNDP report:*…the nuclear industry acknowledges only very limited and closely defined consequences. On the other hand, some politicians, researchers and voluntary movement workers claim that the accident has had profound and diverse impacts on the health of many millions of people…..this uncertainty is a cause of widespread distress and misallocation of resources and needs to be addressed through rigorous and adequately funded international efforts.*[196]

Uncertainties arise for many reasons. It is difficult to make direct comparisons of data before and after the accident, particularly since large scale screening programmes were put in place after the accident which may be picking up cases that would not otherwise have come to light.[197] In addition, rigorous comparisons of data from different areas are not straightforward because of widespread variations in methodology and in many cases, incomplete information on how studies have been conducted.

8.11 Spent fuel storage

In the UK, spent fuel is mainly stored in cooling ponds under several metres of water. This fuel is highly radioactive and is therefore heat-generating. The radioactivity and thus the heat content of spent fuel decays with time, and so varies considerably depending on how long ago the fuel was removed from a reactor and on the type of fuel involved. For example, when fuel is first removed from a reactor it can generate as much as 10% of the heat it generated while in the reactor,[198] but after five years this figure has fallen by a factor of 100 or more. To protect workers and the public from exposure to radiation, several factors need to be taken into account in the design and operation of these cooling ponds. There are several key differences between the on-site and off-site ponds, as explained in Box 8-7.

Security issues associated with spent fuel storage

There are no published analyses relating specifically to the risk of terrorist attacks at UK spent fuel cooling ponds although the issue has been raised by some analysts.[199] It has been discussed more widely in the USA, where many of the existing facilities are storing fuel at higher densities than originally envisaged. This situation has arisen because there is no long term storage facility yet available, and there is no commercial reprocessing of spent fuel. Public concern over the vulnerability of such facilities to terrorist attack has increased over the past three years. A report by the US General Accounting Office (GAO)[200] comes to the conclusion that *widespread harm is possible under certain severe but extremely unlikely conditions involving spent fuel stored in storage pools.* Although the results of such studies cannot be directly applied to UK facilities,

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[195] UNSCEAR, *Health effects of the Chernobyl Accident – results of 15 year follow-up studies,* 3rd International Conference, June 2001. Note that an increased incidence in leukaemia has only been established in workers, and there has been no observed increase in leukaemia incidence amongst the local populations of the worst affected areas.
[196] see reference 181. para 1.27
[197] see 181 para 4.15
[198] Note that this heat is from the decay of radioactive fission products rather than from the fission reaction itself.
[199] Large and Associates, *The implications of September the 11th for the Nuclear Industry,* February 2003.
[200] US General Accounting Office, *Spent Nuclear Fuel: Options to Further Enhance Security,* GAO-03-426, July 2003.

Box 8-7 Spent fuel storage facilities in the UK

At all UK power plants except the Wylfa Magnox plant in Wales, the technique of 'wet-storage' is used (see Chapter 2), where spent fuel is stored in cooling ponds under several metres of water.[201] These are located either within the reactor building (in the case of AGRs) or outside the reactor building inside weatherproof structures. With the exception of Sizewell B, all plants transfer this spent fuel to Sellafield after an initial cooling period of 3-4 months.[202] At Sellafield it is held in wet storage for a further period, pending either reprocessing or a decision on its long term management. Operational off-site cooling ponds at Sellafield are also housed in weatherproof structures.

Safety issues associated with storage of spent fuel

Spent fuel storage must address a number of safety requirements:

- radiological shielding - spent fuel emits ionising radiation (including highly penetrating gamma rays) and must be shielded to prevent exposure of workers or the public to radiation. In a cooling pond, shielding is provided by the water and in the case of dry storage, by the building itself.
- cooling - if the fuel overheated (e.g. by loss of water from a cooling pond) this could lead to degradation of the fuel elements and to release of radioactive fission products. In the case of wet-storage, water keeps the fuel cool and its temperature is controlled by a system of heat exchangers and pumps. In the case of dry storage cooling occurs passively by natural circulation of a gas.
- containment of radioactive material - cooling ponds are made of reinforced concrete 1-2 metres thick and some ponds are lined with steel.
- prevention of criticality (see Box 2-1) - spent fuel still contains some fissile uranium, so if too much spent fuel were brought together, a nuclear chain reaction could be initiated. In a wet-store, depending on the type of fuel, this is avoided by arranging the fuel so that it is not too densely packed, or by adding boron to the water to absorb neutrons.

Design of ponds

Both on-site and off-site cooling ponds currently in operation in the UK are sturdy structures, with concrete walls 1-2 metres thick. There are several differences between the on-site ponds at reactor sites, and the off-site ponds at Sellafield:

- water circulation - in an on-site pond this is maintained by heat exchangers and pumps. In an off-site pond, the fuel has already spent several months at a reactor site, so it is less radioactive and generates less heat than spent fuel at a reactor site. Water can therefore be circulated by convection, without relying on pumps.
- fuel containment - much of the fuel in Sellafield's facilities is not stored as bare fuel elements, but is encased in the inner parts of the steel flasks in which the elements were transported, which provides an additional layer of containment.
- Capacity - on-site ponds can contain several times the amount of fuel in a reactor core, but the amount of radioactivity would depend on how long ago the fuel had been removed and how long it had been left in the reactor. Off-site ponds can typically hold a few thousand tonnes of reactor fuel - tens of times more than a typical reactor core.[203]
- Elevation - off-site cooling ponds at Sellafield are above ground. Some on-site ponds are partially below ground.
- All ponds have been designed to withstand a certain degree of external hazard, for example from earthquakes. In general, the newer ponds are more robust, to cope with the wider range of hazards now considered in their design basis. For example, the cooling ponds at the THORP reprocessing plant at Sellafield have been designed to withstand light aircraft impact.

(for reasons discussed on the next page), the key points are outlined to illustrate the security issues associated with spent fuel storage.

Main conclusions of US studies

- **Physical form** - the GAO report pointed out that *spent fuel is a heavy, ceramic material that is neither explosive nor volatile* and resists easy dispersal. Release of a large amount of radioactive material is *theoretically possible* but would require either a *sustained, high temperature fire* or *an external force such as a high speed impact or violent explosion* in which it was pulverised into small particles.
- **Loss of cooling water** - the GAO report concluded that loss of cooling water was the main means by which a large release of radioactive material might occur from a spent fuel pond.

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[201] At Wylfa, spent fuel is stored in skips and cooled by passive air circulation ('dry-storage').

[202] At Sizewell B all fuel is held on site and is not transferred to Sellafield

[203] International Atomic Energy Agency, *Survey of Wet and Dry Spent Fuel Storage*, TECDOC 1100.

Cooling water acts as a radiation shield, so its loss would mean that the people inside the building could be exposed to highly penetrating gamma rays. Once the water level was below the top of the fuel, direct intervention would be very difficult. In an extreme scenario, sustained loss of coolant could lead to widespread release of radioactive material. Fuel elements could overheat, which could damage the fuel cladding and release gaseous fission products. For some types of fuel, material could be dispersed in a fire (see below).[204]

- **Wet storage versus dry storage:** it is generally agreed that cooling ponds pose a greater risk than dry storage in the US.[205] [206] One reason is that a 'loss of coolant' is not possible in a dry store, because the spent fuel is cooled by natural convection, driven by the heat of the fuel itself.

Loss of coolant scenarios

There are several ways in which loss of coolant could occur from a cooling pond, due either to an accident or to sabotage.

- **Evaporation**: if the cooling systems which extract heat from the cooling water were damaged, the temperature of the cooling water would rise, leading to evaporation. This would take place very slowly and it would probably be several days or weeks before the fuel elements were exposed to air, thus allowing time for remedial action to be taken.
- **Drainage**: this could occur through damage to the network of pipes or tubes connecting the pool to other areas. This would take place more rapidly than first scenario but it is reasonable to assume that there would be a variety of options available for operator intervention before the water level fell below the level of the fuel.
- **Severe damage** to the pond walls or floor - e.g. due to aircraft crash or dropping of a heavy load. This could result in rapid drainage of water from the ponds (see Box 8-7).

Most published reports focus on the last scenario, as it would allow the least time for remedial action. The primary focus of such reports is aircraft impact. Opinions vary about the level of damage that might be inflicted by aircraft impact on a US spent fuel pond. The US NEI has ruled out the possibility of severe damage in such an eventuality (see Box 8-4), while other analysts argue that the effects could be catastrophic.[207] Conclusions depend on factors such as the type and speed of aircraft considered, assumptions made about the effects of aviation fuel, and about the penetration of concrete, as discussed in Box 5-1.

Vulnerability of UK facilities

UK facilities differ from US facilities in many ways - e.g. in design, fuel type and operational practices. This could potentially affect their vulnerability to terrorist attack. For example:

- The average fuel decay time (i.e. the length of time since the fuel was removed from the reactor) is probably lower in the UK than in the US, as spent fuel from AGR and Magnox plants is reprocessed within a few years (see Chapter 9). Hence there will be more short-lived radionuclides present in UK fuel.
- All commercial spent fuel in the US is from light water reactors. US analyses have taken into account the fact that the zirconium cladding on this fuel ignites at 900˚C. In the UK, most spent fuel is from gas-cooled reactors: the stainless steel cladding on AGR fuel is less

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[204] This would depend on whether remedial action could be taken before the elements reached ignition temperatures. The rate of increase in temperature would depend on factors such as fuel age and type (older fuel would take longer to heat up); on how much natural ventilation there was once cooling water were lost (which would depend on the arrangements of the elements within the pool, and the amount of damage to the pool). For fuel which had been freshly removed from a reactor, ignition temperature could be reached within a few hours. Older fuel might take several days to reach such temperatures.

[205] Institute for Resource and Security Studies, *Robust Storage of Spent Nuclear Fuel,* January 2003.

[206] Alvarez et al., *Reducing the Hazards from Stored Spent Power Reactor Fuel in the United States,* 2003.

[207] Alvarez et al., *Reducing the Hazards from Stored Spent Power Reactor Fuel in the United States,* 2003.

flammable than zirconium, while Magnox fuel cladding will ignite and burn at lower temperatures than zirconium.
- Containment differs. In the USA studies the fuel is assumed to be stored as bare elements in 'high-density racks'. The fuel stored on-site at the UK's Sizewell B PWR will be in a similar condition to fuel in US reactor ponds, but much of the fuel stored in off-site cooling ponds at Sellafield has an additional layer of containment (see Box 8-7).
- Some UK ponds are partially or wholly below ground (although most are above ground). It seems reasonable to assume that a cooling pond located below ground level would be less easily damaged than

The US Nuclear Regulatory Commission has recently commissioned Sandia National Laboratory to specifically investigate the potential consequences of various sabotage scenarios on spent fuel cooling ponds, but the results are not yet available.

Consequences of an attack on a spent fuel cooling pond

Even if a terrorist attack succeeded in draining coolant from a pond, such that it could not easily be restored, the amount of radioactive material released and hence the social and environmental consequences would depend on many factors, listed below.

- fuel composition.
- whether the fuel reached a high enough temperature to catch fire before remedial action was taken. The time taken for this to occur would depend on the fuel age and distribution.
- the number of the fuel elements within an assembly catching fire.
- the fraction of the fuel converted into breathable particles (i.e. less than 10 millionths of a metre). There are many uncertainties involved in predicting this fraction.[208]
- the amount of radioactive material remained trapped in the pool or building
- any mitigating measures taken.

There is considerable variation in predictions made by different studies. In the 2001 NRC study mentioned earlier, the authors investigated the effects of an accidental fire in a spent fuel cooling pond. They made the pessimistic assumption that all the fuel assemblies would ignite. For fuel which had been removed from the reactor only 30 days ago, the number of long term cancer fatalities varied from 3,500 to 15,000, depending on the composition of the fuel. This illustrates how the consequences vary depending on fuel composition. The number of early fatalities varied from 2 to 200. For fuel which had been removed from the reactor 10 years ago, the most pessimistic assessment predicted 7,500 long term cancers but no early fatalities.[209]

However, it is difficult to infer from US studies how many people might be affected by a release from a *UK* spent fuel cooling pond due to differences in design, fuel arrangements, fuel type and fuel inventories, and due to the fact that the population distribution around nuclear facilities is not the same in the UK and the USA.

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[208] See for example Luna et al, *Perspectives on Spent Fuel Cask Sabotage,* Sandia National Laboratories, 2001.

[209] More severe effects are predicted by Alvarez et al. (206) which are consistent with earlier studies by the NRC and estimate 54,000-143,000 cancer deaths, loss of 2000-7000 km^2 of agricultural land, and economic costs due to evacuation of several hundred billion dollars. However the NRC has stated that more recent studies indicate spent fuel may be more easily cooled than previously predicted and off-site radiological releases might be substantially reduced from worst-case scenarios quoted in previous reports.

9 Reprocessing plants

9.1 Key points

- Reprocessing has many by-products but published commentary focuses largely on storage facilities for used fuel and for high level liquid waste and plutonium arising from reprocessing, because of the size of the radioactive inventories and the physical state of the material.
- The uncertainty in the likely size of a release from any of these facilities explains the wide range of conclusions in reports in the public domain. For example, some reports widely publicised in the media, predict several million fatalities in the event of a successful attack on the high level liquid waste tanks at Sellafield.[210] These figures are based on 'worst-case scenario' assumptions that over 10% of the total radioactive inventory would be released and that no countermeasures were taken to protect the public.
- While there is evidence that the probability of such a large release occurring *accidentally* lies within established safety limits, there is no equivalent framework for establishing the probability of a large release occurring through deliberate action, and thus it is difficult to place these analyses in context.
- BNFL states that it considers the conclusions of such studies to be unsubstantiated because they are not based on current engineering and construction information, and that on the basis of its own impact assessments (which are confidential) it does not believe *that the physical effects of an aircraft* [on the high level liquid waste tanks] *would result in loss of bulk shielding or containment.*
- Greenpeace have raised concerns over the number of flights passing near Sellafield. Further investigation of this issue would need to take into account any changes made to flight paths since September 11th 2001 as well as measures taken to increase aircraft security.

9.2 Introduction

Reprocessing is the technique by which uranium and plutonium are extracted from spent fuel. It was originally developed to obtain plutonium for military purposes, but later evolved into a commercial activity so that the uranium and plutonium could be re-used in reactor fuel. Commercial reprocessing now takes place only in the UK, France, Japan and Russia.[211] In Europe, the key commercial reprocessing facilities are at Sellafield in Cumbria, operated by BNFL, and Cap de la Hague in Northern France, operated by COGEMA. In addition there are former reprocessing facilities at UKAEA's Dounreay site, which are being decommissioned but which still hold significant quantities of radioactive waste. Facilities at Marcoule in France and at Mol-Dessel in Belgium are also being decommissioned.

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[210] Peter Taylor, *Consequence Analysis of a Catastrophic Failure of Highly Active Liquid Waste Tanks serving the THORP and MAGNOX Nuclear Fuel Reprocessing Plants at Sellafield,* Nuclear Policy and Information Unit, Manchester Town Hall, Manchester, February 1994 ; Commissioned by Strathclyde Regional Council ; City of Glasgow District Council; Nuclear Free Local Authorities (Scotland) ; South Yorkshire Fire and Civil Defence Authority; Bradford City Council, Leeds City Council; Bury Metropolitan Borough Council; Liverpool City Council; Derwentside District Council; Bolsover District Council.

[211] Many other countries discontinued their programmes either on economic grounds or due to changes in non-proliferation policy. The economics of reprocessing are now questionable though they looked good at the time the decision to build THORP at Sellafield was taken in the early 1980's.

Box 9-1 Reprocessing techniques

All commercial reprocessing plants use the PUREX process to reprocess spent fuel. This involves dissolving the spent fuel in concentrated nitric acid, and then using an organic solvent to extract the uranium and plutonium. The plutonium and uranium are then separated from each other in several stages using chemical agents. The outputs of reprocessing are:

- aqueous (water based) solutions of plutonium and uranium, which are purified in several stages and then converted into solids.
- a leftover solution of highly radioactive fission products and actinides dissolved in nitric acid. At Sellafield, this solution is concentrated to produce highly active liquor, or HAL.

About 0.2 cubic metres of HAL are generated for every tonne of spent fuel reprocessed, amounting to several hundred cubic metres per year.[212] HAL is a highly radioactive liquid which also generates significant quantities of heat from radioactive decay. It requires a constant supply of water and electricity to maintain cooling and also a high degree of operator control to keep it in a safe state.[213] At Sellafield and Cap de la Hague there are facilities for 'vitrification' of HAL (conversion into solid form).

This chapter describes the main activities that take place at reprocessing plants and the kinds of radioactive material involved. The main focus is Sellafield, largely because there is considerably more published information about this site than other sites discussed in this chapter. The storage of high level liquid waste, and of plutonium dioxide powder, are discussed in some detail in the context of Sellafield, but the general principles outlined apply to all sites. Published commentary on the potential for terrorist attacks on specific facilities is reviewed. Improvements made to site security and emergency planning arrangements at Sellafield in the past three years are also outlined. Activities at Cap de la Hague, and Dounreay, are briefly discussed.

9.3 Background

Although specific practices vary at different plants, the following activities commonly take place at all reprocessing plants:

- spent fuel handling and storage.
- reprocessing (see Box 9-1).
- treatment and storage of the by-products of reprocessing, including buffer storage facilities for high level liquid waste (HLLW).
- treatment and storage of uranium and plutonium.

Of the above activities, the vulnerability of high level liquid waste storage facilities, and the storage of plutonium, have been widely discussed in the context of both accidental releases as well as terrorist attacks.[214] Public concern focuses on these materials due to the large inventories of radioactive material involved and the fact that they are in a more easily dispersible form than some of the other materials at a reprocessing plant (HLLW is a volatile liquid, and plutonium dioxide is normally stored in powdered form). Spent fuel storage also generates public concern.

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[212] Source: BNFL

[213] HM Nuclear Installations Inspectorate, *The Storage of Liquid High Level Waste at BNFL Sellafield,* February 2000.

[214] See for example *Possible Toxic Effects from the Reprocessing Plants at Sellafield (UK) and Cap de la Hague (France),* a study prepared by WISE-Paris within the STOA (Scientific and Technological Options Assessment) programme of the European Parliament. 2001 ; Institute of Resource and Security Studies (IRSS), *High Level Liquid Radioactive Waste at Sellafield: Risks, Alternative Options and Lessons for Policy*, 1998 ; IRSS, *Hazard Potential of the La Hague Site: An Initial Review,* a report for Greenpeace International, 2000; IRSS, *High Level Liquid Radioactive Waste at Sellafield: Risks, an Updated Review*: 2000; see also references 3,4,88.

9.4 Sellafield

Main activities

The Sellafield site is divided into two parts: Windscale, operated by UKAEA, and the rest of the site, operated by BNFL. Numerous activities take place including spent fuel storage, reprocessing of spent fuel and storage of by-products, MOX fuel fabrication, decommissioning of old facilities, and treatment and interim storage of radioactive waste (see Box 9-2).

Activities at the Windscale site are focussed on decommissioning and waste management. Facilities include the UK's two earliest graphite-moderated air cooled reactors, which were shut down following the Windscale fire in 1957 and are now being decommissioned, as well as a prototype AGR which is almost completely decommissioned. The activities described below relate to those parts of the Sellafield site operated by BNFL.

Spent fuel storage

Spent fuel from the UK's Magnox and AGR plants, and from PWRs overseas, is stored underwater in cooling ponds pending reprocessing. These ponds have a total capacity of ~10,200 tonnes of fuel. In addition, spent fuel from naval reactors is held in storage, but is not reprocessed.[215]

Reprocessing

BNFL state that around 1,500 tonnes of reactor fuel are reprocessed each year. There are two reprocessing plants in operation: the Magnox plant and 'THORP' (Thermal Oxide Reprocessing Plant) which handles AGR fuel from the UK and PWR fuel from overseas. An earlier reprocessing plant relating to the military programme is now being decommissioned. The Magnox plant is scheduled for shutdown in 2012.[216] THORP's closure date will depend on securing future reprocessing contracts.

Plutonium and uranium storage

The plutonium stored at Sellafield and Cap de la Hague is in the form of plutonium dioxide powder. It arises largely from civilian reprocessing. However some is military plutonium which has been transported back to Sellafield by the MoD, because it is surplus to requirements and is now subject to international safeguards (see 3.7). Some plutonium is used to produce MOX, but most is stored pending a decision on its long term management. Almost 80 tonnes were in stock at Sellafield at the end of 2001 and the final inventory is predicted to be ~142 tonnes.[217] The handling of plutonium also gives rise to plutonium-contaminated waste (PCM) destined for conditioning and storage on the Sellafield site. Uranium is also stored on-site. Some of it is transferred back to Springfields fuel processing plant in Lancashire, and re-used.

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[215] www.mod.uk/issues/laesi/section_a.htm

[216] Tight annual targets must be adhered to if the Magnox shutdown date is to be met.

[217] BNFL National Stakeholder Dialogue, Business futures Working Group 3rd interim report (Appendix 10), The Environment Council, July 2003: Of the 80 tonnes in stock as of 2001, 55 tonnes were owned by BNFL. This report states that the expected future programme of reprocessing at Sellafield will result in a final inventory of 142 tonnes of plutonium, 77 tonnes of which will be owned by BNFL.

Box 9-2 Radioactive waste at Sellafield

Activities at Sellafield give rise to hundreds of different types of radioactive waste streams in gaseous, liquid and solid forms. As of April 2001, over 90% of all the high level waste in the UK and roughly 66% of all the intermediate level waste were held at the BNFL Sellafield site.[218] All the high level radioactive waste comes from reprocessing. Low and intermediate level waste streams are generated not only by reprocessing but also by decommissioning. In addition there are legacy wastes which were largely created in the 1950s, 60s and 70s.

All high and intermediate level waste is destined for 'conditioning' - processing into a stable form, suitable for long term management - and less vulnerable to dispersal by terrorist attack than raw waste. Conditioning usually involves immobilising waste in a solid form, encased in stainless steel containers. Sellafield has numerous facilities for short term storage of waste prior to conditioning, facilities for the conditioning of this waste, and for its interim storage pending long term management. Much of the waste at Sellafield is yet to be conditioned and is stored in a raw or partially conditioned state. In general, the conditioning of legacy wastes is more problematic than current arisings.[219]

High level liquid waste (HLLW)
HLLW from reprocessing is transferred from the THORP and Magnox plants to the B215 facility where it is converted into concentrated form known as Highly Active Liquor (HAL) and transferred into Highly Active Storage Tanks (HASTs) where it is held pending 'vitrification' or conversion to a more stable form. As of July 2004, there were 1000-1500 cubic metres of HAL in the tanks. [220]

Vitrification plant
The waste vitrification plant (WVP) came online in 1991 and currently has three operational production lines. It receives HAL from B215 and converts it into solid form by mixing it with glass and pouring it into stainless steel containers.

MOX fuel fabrication
The Sellafield MOX Plant (SMP) facility started to be commissioned in 2001,[221] although commissioning issues have delayed the manufacture of MOX fuel at this facility.[222] A proportion of the plutonium generated by reprocessing is destined for conversion into MOX. The MOX produced will be transported to overseas customers. There are currently no plans to convert existing UK reactors so they can use MOX fuel. [223,224]

Decommissioning activities
Many former military and research facilities on the Sellafield site are currently being decommissioned, including Calder Hall, the site of four early Magnox reactors.

Terrorist threat

There has been widespread commentary on the potential for terrorist attacks at Sellafield over the past three years. A survey of print media coverage (Annex 9) gives further details on how the media have made this association with Sellafield. Media reports tend to focus not on specific facilities at the Sellafield site, but rather on the site as a whole. On the other hand, much of the commentary by environmental groups and NGOs,[225] as well as by local groups, refers to specific

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[218] Nirex, *Radioactive Wastes in the UK: A Summary of the 2001 Inventory*, October 2002.

[219] Under the Nuclear Sites and Radioactive Substances Act 2003, the Nuclear Decommissioning Authority (NDA) will take over responsibility for legacy wastes. A detailed discussion of these plans is beyond the scope of this report.

[220] This backlog has arisen due to earlier problems with the vitrification facility.

[221] Office for Civil Nuclear Security, *The State of Security in the Civil Nuclear Industry*, April 2003-March 2004.

[222] Office for Civil Nuclear Security, *The State of Security in the Civil Nuclear Industry*, April 2003- March 2004.

[223] This issue was raised as part of the BNFL National Stakeholder Dialogue (Plutonium Working Group Final Report, The Environment Council, March 2003) although it was acknowledged that there were *significant hurdles to the use of MOX fuel in existing reactors.*

[224] Light water reactors can be adapted to use Mixed Oxide or MOX fuel, which is a mixture of uranium and plutonium oxides. Up to one third of the fuel in an LWR can be MOX without making substantial modifications to the reactor. Although there are no reactors using MOX in the UK, it is being used increasingly overseas - over 30 reactors in Europe use 30-50% MOX and Japan aims to have 1/3 of its reactors using MOX by 2010.

[225] See reference 214.

facilities, focussing on those which have the *potential* to release large amounts of radioactive material rather than on numerous 'softer' targets that are less well protected, but hold much smaller radioactive inventories.

9.5 High level liquid waste (HLLW) at Sellafield

Background

Highly Active Liquor (HAL) in Sellafield's B215 facility (see Box 9-2) is distributed between 21 HASTs (Highly Active Storage tanks) of which eight were constructed in the 1950s (referred to as HASTs 1-8) and the remainder (referred to as HASTs 9-21) in the 1970s. HAL is a highly radioactive and corrosive liquid which generates significant quantities of heat,[226] although the HAL in HASTs 1-8 is older than the HAL in HASTs 9-21 and so is less active and generates less heat (see below).[227] The key safety requirements are **cooling** and **containment**:

- **Cooling**: the HAS tanks are equipped with internal cooling coils through which water circulates. The newer tanks have a greater number of coils, as well as external cooling 'jackets' and 'agitators' to stir the liquid.[228] Water is supplied from one of two cooling towers on either side of the facility. In accordance with the principle of defence in depth (Chapter 5), there are several backup sources of cooling water as well as backup cooling pumps and power supplies.[229]
- **Containment:** the tanks are made of stainless steel and situated within concrete 'cells' which provide bulk shielding. They have been designed to withstand a range of hazards such as earthquakes but not specifically terrorist attack.

Safety issues

Major safety concerns have been raised by the Nuclear Installations Inspectorate over the past decade, relating to the integrity and safety of the tanks as well as the volume of HAL in storage.[230,231] BNFL were required by the NII to implement a range of improvements which included adhering to strict targets on stock reductions and reducing stock to a buffer level of a few hundred cubic metres by 2015.[232] In addition, the NII requested BNFL to develop operator guidelines for severe accidents, even though some of these scenarios were not *deemed credible.* BNFL state that the safety recommendations made by the NII in 2001 have now been implemented and further improvements are underway. However, some analysts are critical of some of BNFL's practices and also of the NII's approach.[233,234] One of the main concerns raised is that the risks and consequences of large releases of radioactive material have not been properly assessed in the plant safety case, because of their low probability of occurrence.[235]

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[226] HAL contains 99.9% of all the radioactive fission products originally present in spent fuel. Even after the high level waste has been converted into a safe form, it remains highly radioactive and must be isolated from the environment. Such waste will not decay to background levels of radioactivity for thousands of years.

[227] While the temperature of a reactor core is typically a few hundred degrees Celsius, the temperature of the HAL is around 50-60 degrees – so there would be less energy available to disperse radioactive material in the event of a release.

[228] See reference 213.

[229] For example in the event of loss of cooling water from the cooling towers, BNFL states that water could be supplied from the local river Calder or Wastwater supplies (Wastwater is a lake in Cumbria).

[230] See reference HM Nuclear Installations Inspectorate, *Safety of the Storage of Liquid High Level Waste at BNFL Sellafield*', HSE Books, 1995.

[231] See HM Nuclear Installations Inspectorate, *The Storage of Liquid High Level Waste at BNFL Sellafield*, February 2000 and *Addendum to February 2000 report,* August 2001.

[232] Specific points raised by the NII included concerns that the tank cooling systems were not fully independent and that the plant safety case needed to be reviewed and revised. A full discussion is beyond the scope of this report.

[233] IRSS, *High Level Liquid Radioactive Waste at Sellafield: Risks, Alternative Options and Lessons for Policy*, 1998 .

[234] IRSS, *High Level Liquid Radioactive Waste at Sellafield: Risks, an Updated Review*, 2000.

[235] See for example FJ Turvey and C Hone, Radiological Protection Institute of Ireland, Storage of Liquid High-Level Radioactive Waste at Sellafield. An Examination of Safety Documentation, December 2000, http://www.rpii.ie/press/pr200007.html ; references 233 and 234.

Terrorist attacks

The size and nature of any release, in the event of a terrorist attack on the building housing the tanks, would depend on the extent of the damage. Releases could occur in two different ways:

- **Loss of cooling leading to release through the ventilation system:** If cooling were lost for a prolonged period, the liquid in the tanks would overheat, leading to evaporation. The more active HAL would eventually start to boil.[236] In this eventuality, some radioactive material would be released into the atmosphere through the ventilation system. If cooling were lost for several days, the liquid could eventually boil dry leaving a residue of hot radioactive salts (see below) from which volatile elements such as caesium-137 could be released.
- **Breaches in the containment**: If the concrete shielding around them along with the steel tanks containing the HAL ruptured, this would result in release of radioactive material. The tanks might be damaged for a number of reasons: by external impacts or explosions, or as suggested by some analysts, by internal explosions, following prolonged loss of cooling. BNFL states that it '*finds claims of internal explosions to be incredible*'.[237] Several reports suggest that failure of one tank could lead to failure of the surrounding tanks, leading to further releases.

There is considerable controversy about the likelihood of either of these scenarios occurring as a result of terrorist attack. Some discussion of each is given below, focussing on aircraft impact, as this is the mode of attack discussed in most published commentary.

Breach of containment

According to studies carried out by BNFL before 2001, on the possibility of *accidental* aircraft crash, which were cited by the NII in its 1995 report:[238] *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 HAST by flying debris, resulting in the release of HLW into the cell and subsequently a release of radioactivity into the environment.*[239] BNFL estimated that the probability of such an event occurring *accidentally* was 1 in 100 million per year. Because this probability is so low, the tanks were not specifically designed to withstand aircraft impact.[240]

BNFL has carried out updated vulnerability assessments over the past three years. Details of these studies are classified but BNFL has provided POST with a statement (Annex 7) in which it reports that '*The studies provide high confidence that the secondary containment and hence primary containment (which is located within the massive reinforced bulk concrete structure) will survive credible aircraft impact scenarios*'.

There are no detailed independent assessments of the physical robustness of the HAS tanks in the public domain. To carry out such an assessment, detailed information on design and tank

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[236] Reference 231 cites analyses carried out by BNFL which show that the older HAL would not boil on loss of cooling. The report also cites BNFL analyses which show that the more active HAL would take around 12 hours to start boil, if there were no other factors contributing to temperature increase. BNFL state that water supplies would need to be reinstated within 2 days for the tanks containing the most active HAL.

[237] Reports by the IRSS (see reference 233) raise concerns that internal explosions could occur as a result of organic matter accidentally entering the tanks or as a result of build up of gases following a prolonged loss of cooling. In the former case BNFL states that it *finds claims of internal explosions to be incredible given that the HAL contains no organic matter, has low acidity and is stored at standard pressure.*

[238] HM Nuclear Installations Inspectorate, *Safety of the Storage of Liquid High Level Waste at BNFL Sellafield*', HSE Books, 1995.

[239] However, BNFL state that these assessments do not, in fact, *predict* failure of the tanks, but rather *assume* failure of the tanks in order to follow a cautious approach.

[240] HM Nuclear Installations Inspectorate, *The Storage of Liquid High Level Waste at BNFL Sellafield,* February 2000 (2.139)

inventories would be required. This is not publicly available. The Irish government has commissioned an independent assessment of the robustness of the tanks, but there are no further details on this study.

In the event of an aircraft attack, analysts have pointed out that the probability of a breach of containment would also be limited by factors such as the location of the facility and its size.[241] In addition, some of the tanks are partially below ground which might further reduce the chances of a breach.

Loss of cooling

It is difficult to assess the likelihood of prolonged loss of cooling occurring as a result of a terrorist attack. It is reasonable to assume that some damage to the coolant supplies could occur in the event of an aircraft impact (assuming that terrorists targeted the right building) – and that those parts of the coolant delivery system which lie outside the concrete shield surrounding the tanks would sustain the most damage. It is also reasonable to assume that access to the facility might be limited, which could interfere with the provision of backup cooling supplies. The kinds of scenarios that have been suggested, which involve large releases of radioactive material, would require all cooling to be lost for several days. WISE-Paris has suggested that the temperature rise from any jet fuel fire following a plane crash might shorten the time available to take remedial action.[242] BNFL state that the likelihood of such a prolonged loss of cooling is not foreseeable, as it is minimised by the provision of multiple backup systems, and that on the basis of its studies, the risks from potential aviation fuel fires are considered to be low (see Annex 7) .

Consequences of a release

Assuming a terrorist attack did succeed in causing severe damage to the HAS tanks, it is very difficult to predict the consequences of such an event.[243] Predictions vary widely due to differing assumptions about the size and nature of a release, while with studies in the public domain, an incomplete knowledge of technical factors such as the structural response of the tanks adds to uncertainty. There are no published reports quoting source terms for severe accident scenarios, from which parallels could be drawn. The nature of any release would depend on the mode of attack and how material was dispersed. For example, a direct breach of a tank could lead to a liquid release, but a scenario involving prolonged loss of cooling, or a fire, could lead to an atmospheric release. Most published commentary focuses on the latter possibility.

During the land use planning inquiry into the construction of the THORP plant at Sellafield,[244] BNFL presented an analysis of the consequences of a release of 1/10,000 of the tanks' radioactive inventory. An analysis carried out by Taylor[245] prior to THORP's opening considers a scenario where cooling is lost for several days, resulting in 1/10th of the entire inventory of the HAS tanks being released into the atmosphere.[246] WISE-Paris postulates that release of 50% of the entire inventory of radioactive caesium is conceivable.[247] There is not enough information in the public domain to judge how realistic any of these starting assumptions are. Taylor's analysis makes many simplifications and assumptions but it is often cited to provide a broad indication of

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[241] As pointed out by the IRSS in footnote 233 the B215 facility is small in comparison with the reprocessing plants THORP and Magnox, and is located roughly in the centre of the Sellafield site.

[242] WISE-Paris, *Aircraft Crash on Nuclear installations – the Sellafield Case,* October 2001

[243] BNFL state that *for most (if not all) circumstances a release of activity is deemed* [by BNFL] *to be very unlikely*

[244] The Windscale Inquiry, report by Hon Mr Justice Parker, 26th January 1978.

[245] Peter Taylor, *Consequence Analysis of a Catastrophic Failure of Highly Active Liquid Waste Tanks serving the THORP and MAGNOX Nuclear Fuel Reprocessing Plants at Sellafield,* Nuclear Policy and Information Unit, Manchester Town Hall, Manchester, February 1994.

[246] This assumption is drawn from earlier studies carried out for facilities in Germany and the USA rather than on a detailed technical analysis of the HAS tanks.

[247] WISE-Paris, *Aircraft Crash on Nuclear installations – the Sellafield Case,* October 2001

the potential consequences of a large release from the HAS tanks, in the absence of other detailed published work.[248] Some of the main points made were as follows:

- There would be few short term effects from radiation exposure for the general public, because of the small numbers of people living in the vicinity of the site. The main risk to the general public would be long term health effects - for a release of this size, the report concludes that EU thresholds for evacuation could be exceeded as far away as population centres such as Glasgow and Liverpool and thus the analysis predicts hundreds of thousands of people could be affected, even assuming some countermeasures were implemented.[249]
- The scale of the impact varies enormously depending on these countermeasures. In certain cases, the risk of cancer could be reduced by a factor of five by the use of countermeasures such as sheltering and decontamination. If countermeasures were not implemented, the main dose would be from radionuclides like ruthenium and strontium on the skin. If they were, the main dose would be from ingesting food containing caesium-137.
- The author himself points out that the accuracy of his predictions is constrained by limited understanding of the model, the use of over-simplified weather patterns, and assumptions about the kinds of countermeasures that would be introduced and their effectiveness.

BNFL's statement to POST (Annex 7) raises concerns over POST's citing of reports by Taylor, WISE-Paris and IRSS, due to the fact that '*none of the authors of these reports have access to the current engineering and construction information that is necessary to undertake a credible study of the consequences*'.

Actual incidents

There has been only one major incident at a reprocessing plant that actually resulted in a release of liquid high level waste. This was at the Chelyabinsk nuclear complex near Kyshtym in the USSR in 1957, which contained about 80 tonnes of HLLW (under 1/10 of the current Sellafield inventory). Because of problems with the cooling system, the 20 waste-storing tanks at the plant were only intermittently, rather than constantly, cooled, leading to the formation of salts within the tank. These exploded with an energy release of between 5 and 100 tonnes of TNT and resulted in the deposition of radioactive material downwind. The total amount of radioactivity released was around 1/100th the amount released in the Chernobyl accident. Strontium-90 was the major contributor to the long term radiation dose. In the first ten days of the accident, 600 people were evacuated from the settlements in the most severely affected area and about 10,000 people were evacuated from an area of 1,000 km^2 over the following 18 months.[250]

9.6 Plutonium

Plutonium at Sellafield is stored as powdered plutonium dioxide within a facility constructed to withstand a range of external hazards, including certain types of aircraft impact. Plutonium does not generate amounts of heat comparable with HAL and can be cooled either by natural convection or by forced ventilation. Since plutonium falls under international safeguards agreements, operations are closely monitored by international inspectors. It is not possible to comment on the means by which terrorists might attempt to breach such a facility, or their likelihood of success. There are no detailed published discussions of this subject. Nevertheless, some groups have raised concerns about sabotage. Concerns stem from the fact that plutonium is stored in powdered form, and would therefore be more easily dispersed in a fire or explosion,

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[248] A more realistic analysis would require many improvements, such as a more realistic description of the radioactive plume, use of more complex weather patterns as well as updated and realistic contingency planning measures.

[249] Taylor's report does not specifically describe the effects of a release on the population of Ireland.

[250] IAEA information circular, *Report on a Radiological Accident in the Southern Urals on 29 September 1957*, July 1989 (http://www.iaea.org/Publications/Documents/Infcircs/Others/inf368.shtml#table1) .

than a ceramic material like MOX. BNFL recently completed the construction of a protective wall around the plutonium storage facility at Sellafield.

Consequences of a release

As outlined in Box 7-3, the main risk to the public from dispersal of plutonium from the Sellafield facility would be an increased risk of long term cancer through inhalation of fine radioactive particles of plutonium dioxide. The consequences of an attack would depend on the following:

- how much was released, and how much of this was in a ‘respirable’ form. The main risk is from inhaling particles less than a few thousandths of a millimetre across (referred to here as ‘respirable’ particles. Larger particles are not as easily absorbed when inhaled.[251]
- how far it was dispersed before being deposited on the ground. This would depend on chemical form, particle size, the height of any radioactive plume, and weather conditions such as rainfall and wind speed (as outlined in chapter 7). Plutonium might not be carried as far as some other materials - during Chernobyl, most plutonium was found within a few tens of kilometres of the reactor, but caesium and iodine were detected in many countries outside the Former Soviet Union, including the UK.
- how much was inhaled by the population of the surrounding area - this would depend on how close the facility is to major population centres, and on what contingency measures were put in place following the release (e.g. evacuation or sheltering). As explained earlier, Sellafield and Cap de la Hague are located away from major cities.

An article published by researchers at the Lawrence Livermore Laboratory in the US investigates the effects of the dispersal of 200 g of respirable plutonium particles over a typical city, creating a cloud of breathable plutonium particles.[252] Using Munich as an example, which at the time of their analysis, had a population of 4,300 people per square kilometre, the authors estimated there would be ~10 additional deaths due to cancer if residents inhaled particles from the cloud for one hour. The number of cancers would depend how long the plutonium was suspended in the air – on average they estimate a plutonium particle would be deposited within a few days, although this would be speeded up by rainfall or moisture in the air. The assumption made is that any cloud would migrate beyond the city within a few hours (assuming average wind speeds of 5 km/h). In the most pessimistic case, where the cloud did not disperse and the population was exposed for ~4 days before the plutonium settled to the ground, an additional ~20% of the population would develop cancer - though in practice there would be evacuation and sheltering.

Plutonium continues to pose a threat once deposited on the ground as it can be re-suspended in the air. Plutonium isotopes have half-lives of many thousands of years and would therefore pose a long term environmental hazard. Clean-up would be very costly – the clean-up of the weapons accident at Palomares in Spain in 1966 (see section 10.6) cost $100 million.[253,254]

9.7 Other facilities

There are other facilities which also handle large quantities of radioactive material:

- spent fuel (discussed in Chapter 10). In the case of the THORP spent fuel ponds, BNFL state that they are confident that *in the event of an aircraft impact, the weatherproof buildings in which the THORP spent fuel storage ponds are housed would sustain damage but that the*

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[251] Information on the dispersal of plutonium comes from experiments as well as from accidents involving air transport of nuclear warheads containing plutonium in the 1950s and 1960s.

[252] Sutcliffe et al., *Perspective on dangers of plutonium,* Lawrence Livermore National Laboratory,1995 http://www.llnl.gov/csts/publications/sutcliffe/ .

[253] S.Fetter and F. von Hippel, *The Hazard from Plutonium Dispersal by Nuclear Warhead Accidents,* Science and Global Security, Vol 2. pp 21-42, 1990.

[254] This figure refers to the value of the dollar in 1966.

seismically qualified design of the pond and storage arrangements for the fuel (in massive stainless steel flasks stored under metres of water) would minimise the risk of radioactive dispersal.

- vitrified high level waste: Public concerns focus on liquid high level waste rather than on vitrified (solid) waste, because the latter would be much harder to disperse and also because it is passively safe,[255] and cooled to a large extent by the natural air circulation.

The Sellafield site has over 130 buildings containing smaller quantities of intermediate and low level wastes at various stages of conditioning, many of which are several decades old and were not designed to the same robustness as the facilities housing HLLW or plutonium. [256] There has been less commentary on this issue, largely because much smaller radioactive inventories are involved. The consequences of a release would therefore not be as widespread as an attack on the HLLW tanks or a plutonium storage facility. Nevertheless, the issue has been raised by some commentators.[257] There has recently been considerable debate surrounding the condition of a former Magnox spent fuel cooling pond at Sellafield.[258]

There has been considerable public debate about the feasibility of aircraft attack at Sellafield, based on the proximity of the site to commercial and military air routes. Greenpeace have raised concerns over the number of flights passing near Sellafield, and point out that *'it is not known at this stage whether changes to flight paths have been made since September 11th 2001'.* A report commissioned by Greenpeace in April 2002, considered that, based on the fuel load and the type of aircraft involved, the *most significant threat would be from westbound transatlantic flights* and stated that as of October 2001, several hundred such flights passed within 50 nautical miles of Sellafield (although this figure did not take into account any changes in flight routes or aircraft security over the past three years. The report stated that *if* a terrorist did succeed in taking the shortest distance to the target from the planned route, the feasibility of interception appeared to be low, based on the short time available between the reporting of the hijack and the airliner reaching Sellafield. However, the report pointed out that there is considerable route flexibility for these flights, and that '*in the event that hijackers are compelled to fly the aircraft some distance off route the feasibility of interception will increase significantly*'. The report concluded that route flexibility would be *a major deterrent to an airliner hijacking in the heightened security conditions post September 11th'*.[259] BNFL comment that such assessments should also take into account additional security measures put in place since September 11th such as hardened cabin doors and emergency alert systems, which would introduce a time delay in the event of an aircraft being hijacked.

9.8 Emergency planning at Sellafield

As with all nuclear licensed sites, emergency plans are in place at Sellafield which would be called upon in the event of a release. These plans detail both on-site and off-site actions. In the

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[255] Passive safety is where the safety of a system does not rely on operator control or on mechanical systems.

[256] RWMAC/NuSac, *Current Arrangements for the Conditioning, Package and Storage of Intermediate Level Radioactive Waste,* June 2002. The report raised concerns over progress in treatment and packaging of intermediate level wastes, which included 'historic wastes' which may be *'poorly characterised, potentially mobile, physically and chemically degraded, and in 40-50 year old facilities that fall below current standards and are subject to further deterioration'.*

[257] Large and Associates, *The implications of September the 11th for the Nuclear Industry,* February 2003; footnote 256.

[258] See for example HC Deb. 17th July 2003 515W; HC Deb. 21st May 2004 1277 W. This facility was commissioned in 1959-60 for the interim storage of used Magnox fuel. It stopped receiving spent fuel in 1992. Concerns have been raised by the NII over the progress of decommissioning - in 2000 BNFL was required by the NII to retrieve at least 90 per cent. of the potentially mobile intermediate level radioactive waste sludge by 2010. Work is therefore underway to prepare for acceleration of remediation operations. Concerns have also been raised by the European Commission over difficulties in accessing and inspecting the facility, which is subject to inspections under the Euratom treaty.

[259] Personal communication from Greenpeace.

event of an off-site release, emergency plans would be co-ordinated from a district control centre at Summergrove a few miles from the Sellafield site. Off-site emergency planning is the responsibility of the Cumbrian local authority under the 2001 REPPIR regulations,[260] and in practice the local authority has overseen off-site plans since 1993. Although the Sellafield site comprises the UKAEA Windscale activities as well as BNFL, there is a generic off-site plan which applies to events at the entire site.

Detailed emergency plans exist for the area within 2 km of Sellafield – around 40 people live permanently in this area, although the plans take into account the fact that there could be up to 1000 people at a time in the Sellafield Visitors' Centre. All residents within this zone are issued with a leaflet which contains information on actions to take in the event of an emergency. Plans are designed to be extendable to 6 km if necessary (an area within which ~6700 people live). Thus they are designed for a reference accident, which corresponds to the worst case 'credible' accident, rather than a severe accident of the kind discussed previously.[261] The implementation of countermeasures over a wider area would be extremely costly and logistically difficult.

Countermeasures mainly involve sheltering or evacuation of the public. Since the closure of the Calder Hall reactor in spring 2003, it is no longer necessary to issue iodine tablets to the general public as there are no facilities on-site which house material containing significant quantities of radioactive iodine. If evacuation or sheltering were necessary, 'reception centres' (e.g. schools) would be used, where arrangements would be in place to carry out radiation monitoring. Warnings would be issued to the public via sirens, radio and television. BNFL has also set up the 'Criticall' system, whereby in the event of an emergency all householders within a specified radius of the site are automatically contacted by telephone and given an automated message. Box 9-3 describes changes made at Sellafield over the past three years.

Emergency exercises

Annual emergency exercises are held involving all key organisations with responsibilities in the event of an off-site release (including BNFL, Cumbria County Council, the emergency services, utilities, representatives from government and regulators). In 2003, Sellafield's off-site emergency exercise OSCAR-7 was held. The objectives of the OSCAR exercises are primarily to test co-ordination and communication between participating agencies, as well as the operation of the various control centres. Occasionally the general public are involved in aspects of these exercises, although this is not common practice. OSCAR 7 involved testing arrangements for sheltering 300 members of the public in a local reception centre.

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[260] Radiation Emergency Preparedness and Public Information Regulations (see Chapter 11)

[261] The reference accident is currently a failure of a cooling circuit of one of the HAS tanks.

Box 9-3 Examples of changes made at Sellafield since September 11th 2001 [262]

Completed work

- Access: Installation of chicanes; restriction of vehicular access, strengthening of perimeter fences; extension of aircraft exclusion zone.
- Public information: site tours stopped and visitors centre closed (but now re-opened); limited site access for pre-authorised visitors.
- Emergency planning arrangements – over £1 million spent on short term emergency planning measures including the procurement of **a**dditional fire-fighting equipment (similar to that used at airports)
- Enhanced personal search and armed response arrangements for sensitive facilities
- Completion of shield walls to protect specific facilities from aircraft impact
- £20 million spent on enhanced security features.

Ongoing work

- Sellafield 'vital areas' study - started 2003 (see section 6.4).
- Further engineering assessments and vulnerability assessments in conjunction with regulators and other bodies.
- Dialogue - Security Working Group within BNFL stakeholder dialogue (see 6.4).

In general, participants agreed that the exercise ran smoothly, though some areas for improvement were identified including: [263]

- communication with the media: the need to develop a clearer media strategy, and for agencies to brief themselves properly before talking to the media – for example conflicting statements were issued about the level of the incident on the International Nuclear Event Scale (INES – see Annex 6), and over the safety of water in specific areas.
- supply of information: e.g. the need to improve the quality of monitoring data, and to formalise arrangements for the provision of health physics information.
- communication between agencies: e.g. a need to improve the clarity of information exchanged between agencies and for different organisations to be aware of each other's contingency plans. BNFL raised concerns that the NII were not fully informed of BNFL's contingency arrangements for the incident.[264]

9.9 Dounreay

Activities

The Dounreay site was opened in 1955 on a former wartime naval air station, as the centre for UK fast reactor research. Activities on-site are now focussed on decommissioning.[265] It is the site of three earlier reactors (Dounreay Fast Reactor (DFR), Prototype Fast Reactor (PFR) and the Dounreay Materials Test Reactor (DMTR)), as well as numerous associated facilities including former reprocessing plants,[266] research and test facilities, and storage and treatment facilities for radioactive waste.

Safety

A safety audit in 1998 by the NII and the Scottish Environment Protection Agency raised a number of serious concerns about operations – in particular the lack of an effective waste management and decommissioning strategy. The report made 143 recommendations and ultimately led to UKAEA producing the Dounreay Site Restoration Plan (DSRP),[267] which sets out

[262] Source: BNFL

[263] These points have been taken from *Sellafield Level 2 Off-Site Emergency Planning Exercise OSCAR 7*, Exercise Report, 24th September 2003.

[264] See reference 263: Annex A ('Comments from Hot Debrief') : *'No confidence that NII were aware of BNFL's contingency arrangements for the incident'* (BNFL).

[265] Note that the MoD also leases a small part of the site as VULCAN Naval Reactor Test Establishment (Chapter 2)

[266] Reprocessing took place at Dounreay until 1996 when the reprocessing plant was shut down for safety reasons. In 2001 the Energy Minister announced that there would be no further reprocessing at Dounreay.

[267] UKAEA, *Dounreay Site Restoration Plan,* September 2000. See http://www.ukaea.org.uk/dounreay/rplan.htm.

its strategy for decommissioning and waste management over the next ~50 years. The DSRP relies on the construction of various new waste treatment and storage facilities and the transport of some waste and fuel to Sellafield.

Radioactive material on the Dounreay site[268]

The Dounreay site houses significant quantities of nuclear and non-nuclear radioactive material, stored in varying conditions in a range of facilities, the main ones being outlined below:

- **Liquid waste** – there are three types of liquid waste - that from reprocessing,[269] similar to the HAL at Sellafield discussed previously (except that the liquid waste at Dounreay no longer generates heat and falls into the intermediate level waste category); contaminated solvents, also from reprocessing, and sludge from filtering liquid wastes. In its 1999 safety audit, the NII raised serious concerns over the condition of the plant where this liquid waste is housed and identified it as one of the main hazards on the site. Although several improvements have been made, such as the addition of a new ventilation system, removal of waste from this facility has been hindered by safety concerns. Under current plans, some of the waste will be treated in a cementation plant (already constructed).
- **Nuclear fuel** - there are around 109 tonnes of fuel at Dounreay. About a quarter of this comes from the PFR – it has been removed from the reactor vessel and is in interim storage. This fuel contains significant quantities of plutonium. In addition, there are still fuel elements within the DFR vessel, some of which are jammed (see below). Management options for this fuel are being considered.
- **Liquid metal coolant** - both the DFR and the PFR still contain considerable amounts of liquid metal coolant. Work is underway to remove it and new facilities are being constructed for its treatment. The NII point out this coolant poses a hazard as it is reactive in the presence of water and/or air. In the case of the DFR, removal of the coolant is a prerequisite for the removal of the jammed breeder fuel. Timescales on decommissioning of the DFR have slipped from those specified in the site restoration plan.
- **Solid intermediate level waste** - considerable quantities of solid intermediate waste (e.g. fuel element cladding, sludge and contaminated equipment) are housed below ground in facilities used throughout the 1960s and 1970s, which do not meet modern standards. Under current plans this waste will be retrieved, and will then be treated and stored above ground pending a long term management option.

Unlike Sellafield and Cap de la Hague, there is little detailed published commentary on the risk of terrorist attacks at the Dounreay site although there have been numerous reports on-site security in the media over the past three years. As explained earlier in this report, the vulnerability of specific facilities to sabotage will depend on security arrangements as well as on factors such as their accessibility, their structural integrity and the type of material they contain.

9.10 Cap de la Hague

The French reprocessing facility at Cap de la Hague is operated by the French nuclear operator COGEMA and reprocesses fuel from French plants as well as from other European countries and from Japan. As at Sellafield, the main facilities on-site are:

- spent fuel cooling ponds (five being operational).
- three reprocessing plants.
- facilities for treatment and storage of high level radioactive waste (tanks for storage of liquid high level waste, vitrification facilities and storage facilities for vitrified waste).
- facilities for treatment and storage of uranium and plutonium arising from reprocessing.

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[268] Health and Safety Executive, *Safety Audit of Dounreay,* Final report 2001, http://www.hse.gov.uk/nsd/auditfin.pdf .

[269] Almost 200 cubic metres according to NIREX radioactive waste inventory 2001.

- facilities for treatment and storage of various types of intermediate and low level radioactive waste.

Vulnerability assessments

Various reports by NGOs[270] have discussed the potential for, and the consequences of, hazardous events (i.e. accidents or malicious acts) but there have been no detailed vulnerability assessments published by COGEMA or by the French nuclear regulators. Although there are various design characteristics and operational procedures specific to La Hague, the factors affecting the risks and consequences of a terrorist attack at the site are broadly similar to those already discussed in this report, in the context of Sellafield. According to the Institute for Resource and Security Studies, the volume of liquid high level waste at Cap de la Hague has been reduced to a few hundred cubic metres – less than one-fifth that stored at Sellafield.[271] Published reports focus primarily on the storage of spent fuel and plutonium.

It is generally agreed that a thorough analysis of the hazard posed by the Cap de la Hague site cannot not be carried out using the information available in the public domain. To do this, detailed design information would be required as well as information on current inventories of radioactive material. The IRSS argues that such information should be made available, and its absence leads on many occasions to an incomplete understanding of safety issues.[272]

9.11 Issues

International variations in policy on reprocessing and spent fuel management

As pointed out by IRSS, safety issues relating to the operation of reprocessing plants and spent fuel storage facilities have been debated for several decades and policy decisions vary in different countries. For example, in the 1980s there was considerable public controversy surrounding an application by the German nuclear operator DWK to construct a reprocessing plant at Gorleben in Niedersachsen, which would have been similar to the Sellafield and Cap de la Hague plants. Following a public debate, the state government ruled that the proposed stores of HLW and spent fuel constituted a ‘large hazard potential’ because of their large radioactive inventories, and that it was not willing to issue a licence to such a facility unless the following criteria were satisfied:

- The cooling of spent fuel should not depend on ‘the functioning of technical equipment or on human reliability’.
- Highly radioactive wastes should not be stored in liquid form in normal operation and buffer tanks, if necessary should be made inherently safe’.

As a result of this ruling, all ‘away from reactor’ spent-fuel storage facilities in Germany use dry storage techniques.

Future radioactive waste management options in the UK

There is currently no long term management strategy for intermediate or high level radioactive waste in the UK. As pointed out in the House of Lords Science and Technology Committee report on Radioactive Waste in 1999,[273] there is only a limited number of viable options:

- indefinite on or near surface storage - once waste has been conditioned, one option is to leave it in interim storage facilities in the hope that new management solutions will become

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[270] See for example *Possible Toxic Effects from the Reprocessing Plants at Sellafield (UK) and Cap de la Hague (France),* a study prepared by WISE-Paris within the STOA (Scientific and Technological Options Assessment) programme of the European Parliament., 2001 ; *Hazard Potential of the La Hague Site: An Initial Review,* IRSS, 2000

[271] IRSS, *Hazard Potential of the La Hague Site, an Initial Review,* May 2000.

[272] See footnote 271.

[273] House of Lords Science and Technology Committee, 3rd Report, Session 1998-1999, *Management of Nuclear Waste,* March 1999.

available in future. However, the Committee pointed out that this would necessitate continued supervision as well as repackaging of wastes and maintenance of facilities.

- emplacement in geological formations - this option is already being pursued by countries such as the USA (the planned Yukka Mountain repository for high level waste) and Finland, where plans are underway for a deep geological repository for spent fuel at Olkiluoto. The option of 'phased disposal', where waste is retrievable, in principle, for an initial period, is favoured by many countries[274] and has been recommended by the House of Lords Science and Technology Committee.[275] It has also been incorporated into the design of a deep geological facility developed by Nirex for the safe long-term management of radioactive waste in the UK.

Additional technological approaches are under investigation, but whether any of these will eventually be used is currently uncertain. One option is partitioning and transmutation (P&T), which would involve separating long-lived radionuclides and converting them into short-lived radionuclides. However the Radioactive Waste Management Advisory Committee[276] recently concluded that *P&T does not represent a comprehensive solution to the radioactive waste management problem* on the grounds that it would be costly to develop, could manage only a small fraction of the UK's waste and would necessitate the operation of facilities which would require a continued commitment to nuclear power (e.g. reprocessing plants and nuclear reactors).

Other options considered in the past but no longer regarded as viable include disposal at sea (now outlawed by international convention); disposal in ice sheets (also prohibited by international treaties); disposal in subduction zones[277] and ejection into space (rejected on the grounds of both cost and safety).

Policy developments

Possible management options have been under discussion for many decades.[278] In 1997, an application by Nirex to build a Rock Characterisation Facility near Sellafield to investigate options for a future waste repository was rejected following a public inquiry. After this, in its White Paper on 'Managing Radioactive Waste Safely' in 2001, DEFRA proposed a comprehensive review of all disposal options and a national debate on what should be done with radioactive waste.[279] The Committee on Radioactive Waste Management (CoRWM) has been set up to co-ordinate this debate.

In their responses to the DEFRA consultation, the House of Lords Science and Technology Committee[280] and the Royal Society[281] both stressed the need for a radioactive waste management strategy in the light of heightened terrorist threats. The Lords Science and Technology Committee stated that *the new awareness of terrorist threats to vulnerable installations simplifies things by leaving deep underground storage as the only realistic option* and called for *early action to make the present surface stores of radioactive material less vulnerable.*

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[274] EC Community Research Project Report, *Concerted Action on the Retrievability of Long-lived Radioactive Waste in Deep Underground Repositories,* Euratom Ref. EUR 19145 EN ,2000.

[275] House of Lords Science and Technology Committee, First Report, Session 2001-2002, *Managing Radioactive Waste: the government's consultation,* November 2001.

[276] Radioactive Waste Management Advisory Committee, *The Radioactive Waste Management Advisory Committee's Advice to Ministers on the Application of Partitioning and Transmutation in the UK,* December 2003.

[277] Defined as an area where the earth's oceanic crust slides beneath another piece of crust.

[278] Royal Commission on Environmental Pollution, Sixth Report, *Nuclear Power and the Environment,* 1976.

[279] DEFRA, *Managing Radioactive Waste Safely,* September 2001, http://www.defra.gov.uk/environment/consult/radwaste/default.htm

[280] See reference 275.

[281] The Royal Society, *Developing UK Policy for the Management of Radioactive Waste,* 2002.

In the UK, certain materials such as plutonium, uranium and spent fuel are not currently classified as waste, although the possibility of reclassification of some waste in future was raised in *Managing Radioactive Waste Safely.* In the case of plutonium, further conditioning would be needed, which would minimise the risk of future misuse (e.g. to construct a radiological or nuclear device). One possible option is to immobilise plutonium in glass or ceramics.[282] BNFL states that it is investigating the possibility of immobilising some plutonium which has '*no future nuclear use*'. Another suggested option is to shield plutonium in high level waste which would act as a radiation barrier, but there are currently no countries investigating this option.

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[282] Note that the US Department of Energy sponsored a Plutonium Immobilisation Program in the 1990s to investigate immobilising plutonium in a ceramic matrix, but this was suspended in 2001 pending review of management options for US plutonium.

10 Transport of radioactive material

10.1 Key points

This chapter provides an overview of what is publicly known about the risks and consequences of terrorist attacks on shipments of radioactive material. Key points are:

- Up to half a million packages containing radioactive material are transported in the UK each year. Most contain relatively small quantities for medical, industrial or research use. Civilian nuclear power and some military activities give rise to a relatively small number of shipments of much larger amounts of material.
- A few hundred shipments of spent fuel from power plants each year account for over 99% of the total amount of radioactivity transported in the UK.
- UK safety regulations are based on international standards which specify the type of package according to the amount and type of material involved. Packages used for more radioactive materials such as spent fuel are subject to fire, immersion, crash and puncture tests.
- UK security regulations are designed to address the risks both of theft and of sabotage and specify transport arrangements based on IAEA guidelines.
- Shipments of radioactive material involve much smaller amounts of material than those held in the fixed installations discussed earlier, but can pass close to major population centres.
- A full analysis of the risks and consequences of a terrorist attack on a shipment of a radioactive material would require detailed information on design specifications and the physical response of containers as well as information on security arrangements, most of which is classified.
- The results of published analyses vary widely depending on assumptions made about flask response and the amount of material released. Studies carried out by WISE-Paris indicate that an attack or accident involving a spent fuel flask could affect an area as small as a few tens of metres across or as large as a few tens of kilometres (in a worst case scenario).

10.2 Introduction

This chapter discusses what is known about the risks of terrorist attacks involving shipments of radioactive material.[283] Section 10.3 outlines the regulations in place to minimise safety and security risks and provides more detail on the type of risk that security regulations aim to address. The different types of shipment taking place in the UK are detailed in Box 10-3. Sections 10.4 to 10.8 discuss certain types of shipments which give rise to particular public concern, including the transport of spent fuel through populated areas, and international sea shipments of radioactive materials. Section 10.9 discusses the amount of information available in the public domain.

10.3 Regulation of transport of radioactive material

As with a fixed nuclear facility (e.g. a power plant) regulations are in place to address the risk of people being exposed to harmful levels of ionising radiation, as a result of the transport of radioactive material:

- Safety regulations aim to control the risk of exposure during normal operations (e.g. through handling packages) and accident conditions (for example accidental dispersal of radioactive material following a severe impact or fire). Safety regulations apply to all radioactive materials, whether or not they are nuclear.
- Security regulations aim to control the risk from terrorist acts: e.g. theft of material to create an explosive device, or sabotage of a shipment to disperse radioactive material. There are

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[283] The word ‘shipment’ is used to refer to all transports, not just those taking place by sea.

separate security regulations for nuclear and non-nuclear radioactive material (as defined in Box 2-1).

Safety regulations

Safety standards in the UK are based on IAEA regulations.[284] Certain package designs and shipments carrying relatively large quantities of radioactive material must be approved by the Department for Transport. A range of organisations is involved in enforcement of regulations, depending on the mode of transport.[285] There are five separate categories of package.[286] For each category, regulations specify the maximum radioactive content and the physical tests that the package must satisfy. For a given shipment, regulations specify the kinds of package that can be used, based on the properties and quantity of radioactive material involved. The higher the category, the more stringent the regulations. In order of increasing hazard, these categories are:

- excepted packages - these can be handled as ordinary packages. They do not require external labelling and do not need to carry the radioactive trefoil symbol (see Figure 10-1). Typical contents are radioisotopes for medicine and research – for example radiopharmaceuticals or experimental apparatus.
- Industrial - these packages and the vehicles transporting them must carry the radioactive symbol. Typical materials include uranium ore (which is only weakly radioactive), or waste, e.g. disposable gloves or clothing which have been worn when working with radioactive materials. Neither excepted nor industrial packages are designed to withstand accidents, but depend for safety on strictly limiting the specific activity[287] of the material they are permitted to carry.
- type A - these packages are subjected to tests to withstand normal transport conditions including rough handling or rainfall. They must also withstand minor accidents. Typical contents are medical isotopes. Type A packages often involve materials with short half lives and are often transported by air to ensure fast delivery.
- type B - these are used to transport relatively large quantities of radioactive materials such as spent fuel, fresh MOX and plutonium, or non-nuclear highly radioactive sources used in e.g. medicine and industry. They must be able to withstand a wide range of accident conditions and to satisfy tests including immersion, fire, impact and puncture, discussed in section 10.5.
- type C - a category introduced in 1996 specifically for air transport of relatively large quantities of radioactive material including MOX and plutonium. However, the Department for Transport state that there have been no requests for approval of Type C shipments in the UK since this category was introduced.

Figure 10-1 The radioactive trefoil symbol

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[284] IAEA, Regulations for the Safe Transport of Radioactive Material, Safety Standards Series, 1996.

[285] Air (Civil Aviation Authority); Sea (Maritime and Coastguard Agency) ; Rail (Health and Safety Executive) ; Road (Department for Transport) ; Military shipments (Ministry of Defence). These agencies are responsible for overseeing emergency planning arrangements for accidents involving their respective modes of transport.

[286] See http://www.nrpb.org/understand/transport/transport.htm

[287] activity per unit mass.

The test requirements for all packages are designed primarily to protect workers and the public during normal and accident conditions. However, some aspects of the package design will also provide defence against terrorist attack. Nevertheless, some reports suggest that in extreme situations terrorists might be capable of piercing or rupturing certain types of package including the robust 'Type B' packages.[288] [289] This issue is discussed further in section 10.5.

Security regulations

In the UK, security arrangements for transport of nuclear material have been regulated by OCNS since the introduction of the Nuclear Security Regulations 2003, and are based on IAEA guidelines on the Physical Protection of Nuclear Material (Box 10-1).[290] Transport of radioactive, non-nuclear material (e.g. radioisotopes for medicine and industry) is regulated by TRANSEC, within the Department for Transport.

Security arrangements

Details of arrangements are limited for security reasons. Some information on military arrangements for Local Authorities and Emergency Services (LAESI) is published by the Ministry of Defence.[291] Defence nuclear materials comprise shipments of nuclear weapons, special nuclear materials and used and new submarine fuel. Transport of such materials by road and rail takes place accompanied by a convoys of varying size (up to 20 for nuclear fuel, 30 for special nuclear material and 50 for road transport of nuclear weapons). These convoys include radiation monitoring experts as well as fire crew and a first aid team. Local police are notified in advance of the shipment passing through their area. Shipments by air are carried out with RAF response teams at a number of bases along the flight route

There is no equivalent source of information about security arrangements for civilian transport. OCNS state that unclassified press reports, agreed by OCNS, may be issued as appropriate in advance by civil nuclear operators when certain materials are to be moved and that sensitive details will also be made available to the police and other public bodies as appropriate.

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[288] WISE-Paris*, The Transports in the French Plutonium Industry*, commissioned by Greenpeace, February 2003.

[289] United States General Accounting Office, *Spent Nuclear Fuel: Options to Further Enhance Security,* July 2003.

[290] International Atomic Energy Agency, *The Physical Protection of Nuclear Material and Facilities*, Information Circular 225, 4th revision. www.iaea.org/worldatom/Programmes/Protection/inf225rev4/rev4_content.html

[291] The Ministry of Defence publishes some information on contingency arrangements for the benefit of local authorities and emergency services*.* See *Local Authority and Emergency Services Information,* Ministry of Defence, 2002 (http://www.mod.uk/issues/laesi/)

Box 10-1 IAEA requirements for physical protection of nuclear material during transport

The IAEA guidelines on the *physical protection nuclear materials* contain recommendations relating to the transport of nuclear material. These guidelines do not apply to non-nuclear radioactive materials.

The guidelines state that the transport of nuclear material is probably the operation most vulnerable to an attempted act of unauthorized removal of nuclear material or sabotage and that the level of protection should take into account the State's Design Basis Threat, the physical protection should be in depth and particular attention should be given to the recovery of missing material.

The following general principles are recommended:

- minimizing the total time that the nuclear material is in transit.
- minimizing the number and duration of nuclear material transfers.
- avoiding the use of regular movement schedule.
- vetting of individuals involved in transport operations.
- limiting advance knowledge of transport information to the minimum number of persons necessary.

The guidelines are designed to allow some flexibility in interpretation. For example, they state that appropriate measures, consistent with national requirements, should be taken to protect the confidentiality of information relating to transport operations, but do not actually prescribe what these measures should be. The recommendations do not stipulate the mode of transport that should be used in different circumstances, nor do they specify the kinds of containers that must be used in each case. These are addressed by safety regulations as discussed in the previous section.

Packages fall into three categories depending on the quantity and type of material being transported. Recommendations vary depending on the category involved.[292] Category 1 shipments have the most stringent security requirements including:

- accompaniment by guards. The guidelines say *states are encouraged to use armed guards to the extent that laws and regulations permit.* In the case of road transport, each loaded vehicle must have its own guard, as well as being accompanied by another vehicle. If overnight stops are necessary, they must be in guarded buildings.
- provision of a transport control centre to monitor progress and maintain communication.
- emergency response - there should be arrangements for a response force to arrive in time to prevent theft or sabotage.

Other measures which apply to all categories include:

- notification of the receiver of arrangements in advance.
- provision of locks and seals on containers.
- using closed vehicles for all packages under 2000 kg.
- searching vehicles before transport.

Types of security risk

Security regulations are designed to address the threat both of sabotage of shipments, and of theft of material by terrorists. A range of factors needs to be considered when assessing the security risk associated with a given shipment. In the case of direct sabotage, which is the main focus of this report, one would need to consider:

- the amount of radioactivity involved - this would depend on the amount of material and its radioactivity per unit mass. Discussions in published literature generally focus on large radioactive inventories such as spent reactor fuel and bulk shipments of radioisotopes.
- the robustness of the containers to attack - packages are designed to withstand a range of accident conditions which provide a degree of protection against sabotage. However, even the more robust 'Type B' packages might not withstand extreme situations such as attack with anti-tank missiles.[293]
- how easily the material might be dispersed - this would depend on its physical form – for example its flammability, or whether it were in powdered form (e.g. plutonium dioxide) or ceramic form (e.g. MOX).
- distance from centres of population.

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[292] As defined in Box 3-2.

[293] United States General Accounting Office, *Spent Nuclear Fuel: Options to Further Enhance Security,* July 2003.

Similarly, a range of factors needs to be considered when assessing the risk of theft, outlined in Box 10-2. Specific risks associated with each type of shipment are outlined in Box 10-3.

10.4 Case studies

The following types of shipment arouse particular public concern, due to factors such as the amount and type of radioactivity involved, or proximity to towns and cities:

- transport of spent nuclear fuel.
- transport of separated plutonium.
- transport of nuclear weapons.
- sea shipments of MOX, high level waste, plutonium and spent fuel.

These case studies are discussed in more detail in sections 10.5 to 10.8, drawing on information not only from UK studies but also from overseas studies conducted in the USA and France.

Box 10-2 Theft of a nuclear weapon or radioactive material

Theft of a nuclear weapon, or theft of material to construct a nuclear weapon

As discussed in the introductory chapters, certain isotopes of plutonium and uranium ('fissile isotopes') can sustain nuclear chain reactions, which are the principle behind nuclear weapons. In addition to the threat of terrorists procuring nuclear weapons, terrorists might attempt to construct a device using a range of materials containing fissile plutonium or uranium (e.g. MOX, plutonium dioxide powder, used or fresh reactor fuel). The following factors need to be considered when assessing the risk:

- the amount of processing the material would require before it could be used in a nuclear device. Not all candidate materials are in a form suitable for immediate use in a nuclear device. For example, low enriched uranium (LEU) can contain a few percent of uranium-235, which can fuel a nuclear chain reaction. However uranium needs to contain over 20% uranium-235 for use in a nuclear weapon, so chemical enrichment would be necessary. However, construction of facilities to chemically enrich LEU to weapons grade uranium would be a large scale operation well beyond the means of a terrorist group.
- technical challenges associated with constructing the device. Construction of any nuclear weapon would be technically challenging for a terrorist group, even though some analysts argue that there is sufficient publicly available information to design one.[294] For technical reasons it would be far easier for terrorists to construct a device based on uranium than one based on plutonium.
- the amount of material that would be required. This would vary depending on the type of material and the percentage of the fissile isotope.

Theft of radioactive material to construct a radiological device

Radiological terrorist attacks involve dispersal of radioactive material without a nuclear explosion. They pose far fewer technical difficulties than deploying a nuclear weapon. The following factors would have to be taken into account in assessing the threat:

- the amount of radioactivity involved.
- the ease of handling the material - this would depend on how radioactive the material was and whether it needed heavy shielding to be handled in safety.
- The ease of dispersing the material - as with sabotage, this would depend on the physical properties of the material – for example its physical form, its flammability or its volatility.

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[294] See for example '*The New Terrorist Threat*' Institute for Science and International Security, August 1997.

Box 10-3 Types of shipment and discussion of risk

Nuclear fuel cycle – 'front-end'

The following materials are involved in the production of fuel for nuclear power plants. They involve either natural or low enriched uranium (LEU), which is unsuitable for use in nuclear weapons. Uranium is weakly radioactive, so these materials would not pose a major radiological hazard if dispersed. However since uranium is a heavy metal they pose a chemical hazard.

- **Uranium ore concentrate (UOC)** is shipped in to various UK ports from overseas and transported by road to chemical plants where it is processed to produce uranium hexafluoride.
- **Uranium hexafluoride (HEX)** is used to make nuclear reactor fuel. It is transported by road between enrichment facilities and fuel fabrication facilities.
- **Fresh nuclear fuel (for power plants)** is transported by road from fuel fabrication facilities to nuclear power plants. The fuel is either in the form of ceramic pellets or metallic form, both of which would be difficult to disperse, and would have to be extracted from the metal fuel pins which encase them.

Nuclear fuel cycle – 'back end'

- **Spent nuclear fuel** is transported to Sellafield from UK AGR and Magnox plants, from overseas plants via UK ports, and from naval bases, n heavily shielded transport flasks. The main threat is of terrorists attempting to sabotage a shipment to disperse radioactive material. Because spent fuel is highly radioactive and requires thick shielding, terrorists could not easily handle it to make a radiological or nuclear weapon.
- **Separated plutonium** may be transported as part of the civilian nuclear power fuel cycle, or in small quantities for use in research, or for military purposes (section 10.6). Construction of a nuclear device would be easier with military plutonium than with civilian plutonium (see Annex 1). Since plutonium is transported in powdered form, it could be dispersed more easily than ceramics such as MOX or spent fuel. Due to its radioactivity and long half-life, it would have a greater radiological impact than uranium. The radioactivity emitted by plutonium is not highly penetrating, so it does not require thick shielding.
- **Radioactive waste** (in the UK only Very Low Level Waste [VLLW] or Low Level Waste [LLW] is transported, typically in industrial packages. More highly radioactive wastes (Intermediate and High Level Waste) generally stay on-site, as there is currently no long term management strategy for them.
- **Mixed Oxide Fuel** contains a mixture of plutonium and uranium. To construct a nuclear weapon using MOX fuel, terrorists would first have to extract the plutonium from the MOX, which would present considerable technical challenges. Some analysts believe that if a terrorist group had the technical capability and expertise to construct a nuclear weapon from plutonium it would also have the technical capacity to extract plutonium from MOX.[295]

Radioisotopes

- **Radioisotopes in exempt or industrial packages** contain relatively small amounts of radioactivity and their dispersal would not have a major environmental or health impact though it could lead to widespread panic. **Radioisotopes in 'Type A' packages** typically include materials used in agriculture and industry and involve more material than exempt or industrial packages, but much of this material is not in an easily dispersible form (e.g. in the form of metallic capsules)
- **High Activity Sealed Sources** include non-nuclear radioactive sources (e.g. radioisotopes for medical or industrial use) whose activity exceeds a specified threshold. Sources at the lower end of the activity range can be transported in 'Type A' packages but the rest would be transported in 'Type B'. Dispersal would have a more widespread impact than other types of package containing radioisotopes.[296]

Military

- **Fresh nuclear fuel (for submarines)** is transported by road from fuel fabrication facilities to naval bases. It is made from HEU which could be used to make nuclear weapons although security surrounding military shipments is very tight. Like LEU, dispersal of HEU would not be straightforward due to its physical form. However, if dispersed, it poses more of a radiological hazard than LEU as it contains a higher fraction of the isotope U-234, which is more radioactive than the other isotopes.[297]
- **UK nuclear weapons** are transported by road under tight security. Weapons are designed with multiple safety systems to prevent unauthorised or accidental nuclear explosion.[298] (See section 10.7).

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[295] BNFL National Stakeholder Dialogue, Plutonium working group final report, The Environment Council, March 2003.

[296] Additional measures were introduced in 2003 to strengthen control over High Activity Sealed Sources (HASS). In December 2003 an EC directive was adopted in the UK which includes a number of provisions that must be satisfied before holders can be granted a licence. Holders must demonstrate that arrangements are in place for safe management of the source even when it is disused and contingency arrangements must be in place for dealing with orphan sources. The directive defines HASS as sealed sources causing a dose exceeding 1 mSv/h at a distance of one metre.

[297] Royal Commission on Environmental Pollution, Sixth Report, *Nuclear Power and the Environment,* 1976.

[298] A nuclear explosion can only occur if the conventional chemical explosives used in nuclear weapons are detonated in a very precise manner by the simultaneous initiation of a number of detonators with an electrical firing signal.

10.5 Transport of spent nuclear fuel[299]

Spent fuel accounts for 99% of the total radioactivity transported in the UK each year. It is taken to Sellafield from UK power plants,[300] from overseas power plants via various UK ports[301] and from naval bases. Apart from the occasional road shipment from HMS Vulcan in Scotland, spent fuel is mainly transported by rail within the UK. Shipments also take place in many other countries.

Design of flasks

As spent fuel is highly radioactive and emits penetrating gamma radiation, transport flasks are designed to provide thick shielding as well as to withstand a range of accident scenarios. In the UK, spent fuel is transported immersed in water in special flasks which are among the most robust containers in frequent use for transport of radioactive material. They are several metres long, over two metres in diameter and consist of one or more layers of steel or lead some tens of centimetres thick (see Figure 10-2). Spent fuel flasks fall into the category of 'type B' packages which must remain intact under the following tests on undamaged flasks:

- a drop from 9 metres onto a rigid surface[302]
- a drop from 1 metre onto a steel spike 15 cm wide.
- immersion under water - typically for 8 hours under 15 metres of water, but also in deeper water for shorter periods. Flasks which are destined for sea shipment must withstand more stringent immersion requirements.
- a fire of 800 degrees Celsius for up to 30 minutes.

The design of flasks is broadly similar worldwide because the package tests are international, based on IAEA standards. Tests are not carried out for every single flask, but on test flasks and scale models. The CEGB conducted a high profile test in the 1980s involving a crash between a spent fuel flask and a train that hit the stationary flask at over 100 miles an hour. The locomotive disintegrated but the spent fuel flask suffered only minor damage. Nevertheless, some reports raise concerns that package tests for spent fuel flasks (particularly the impact and fire tests) are not stringent enough and that tests on scale models are not as reliable as full scale tests.[303] However there are currently no plans to modify design requirements for spent fuel flasks in the UK. The flasks that are currently in use cost of the order of £1-2 million each, and are designed to last for 20-30 years. Any replacement would be very expensive.

Flasks are not specifically designed to withstand terrorist attack but safety requirements will provide defence against them. Tests have been carried out in the USA on the ability of spent fuel flasks to withstand certain types of artillery but there is no published information on whether such tests have been performed in the UK. In the USA, although there is a broad consensus that certain types of artillery could pierce US spent fuel flasks, there is controversy over whether the breach would cause a significant release of radioactive material (Box 10-4).

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[299] http://www.british-energy.com/education/factfiles/items/item46.html

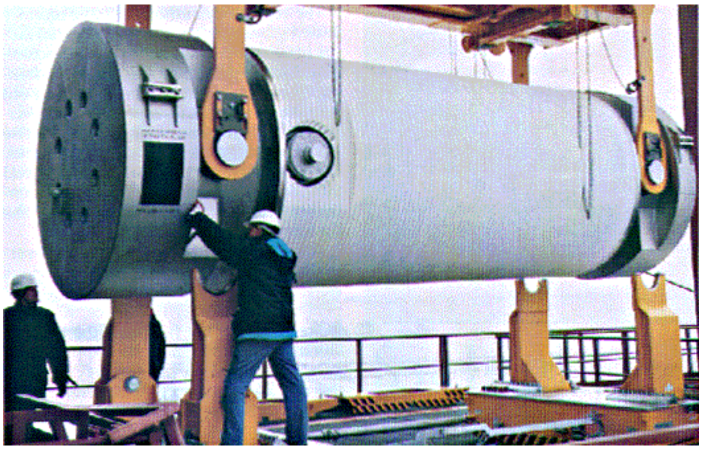
[300] All UK power plants except Sizewell B where it is held on site.

[301] A total of 900 flasks are transported to Sellafield by rail each year, not including international shipments.

[302] This is roughly equivalent to a crash at 120 miles per hour.

[303] Nuclear Waste Trains Investigative Committee, Greater London Authority, *Scrutiny of the transportation of nuclear waste by train through London,* October 2001.

Figure 10-2 A spent fuel flask



Source: Uranium Information Centre (***www.uic.au***)

Risk assessments in the public domain[304] [305]

It is not possible to make accurate predictions about the consequences of a terrorist attack on a spent fuel shipment, since even if one assumes a given attack scenario (see section 10.3) assumptions have to be made about factors including flask response and the amount of radioactive material released in the event of a breach of containment. There are no publicly available assessments for UK spent fuel flasks. However, because flasks are designed to similar specifications worldwide, studies conducted overseas can provide some insight into the issue. Box 10-4 discusses studies conducted in the US and France.

There are two issues to consider when transporting any hazardous material. On the one hand, it is desirable to transport material via the most direct route, thus minimising transit time. On the other hand, it is desirable to avoid major population centres, but these often lie on the most direct route. The transport of spent fuel close to major population centres gives rise to a considerable amount of debate.[306] In the UK, the transport of spent nuclear fuel in the South East and through London is a particularly controversial issue and was the subject of an inquiry by the Greater London Authority in 2001 (Box 10-5).

The impact of an attack on a spent fuel flask would depend on the type of fuel being transported for reasons listed below. However a detailed analysis of the impact of an attack on the different flask types would be needed to draw conclusions.

- **Flask type** AGR, Magnox and PWR fuel are each transported in different types of flask – for example, some are monolithic (one thick layer of containment) while others have two thinner layers. Thus they might have different susceptibilities to attack by terrorists (e.g. with artillery).
- **Fuel type** In an extreme situation, involving a fire as well as breach of a flask, different types of fuel would respond differently. The extent to which the fuel elements were degraded would also depend on the fuel cladding. For example, Magnox fuel cladding is flammable at 500 degrees Celsius, while the zirconium cladding on PWR fuel will not ignite until temperatures

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[304] United States General Accounting Office, *Spent Nuclear Fuel: Options to Further Enhance Security,* July 2003.

[305] See reference 303

[306] The transport of spent nuclear fuel has been the subject of numerous Parliamentary questions. See for example HC Deb, 29th Jan. 2004, col.502W ;18th Nov. 2003, col. 733W ;15th Oct 2002, col. 709W; 22nd July 2002, col. 785W.

exceed 900 degrees Celsius. AGR fuel cladding is made of stainless steel, which is even less flammable than zirconium.

Box 10-4 Overseas studies of spent fuel transport

Transport of spent nuclear fuel in France
A report by WISE-Paris[307] postulated various accident scenarios involving spent fuel transport in France.[308] WISE-Paris did not carry out detailed technical analyses to estimate the amount of material released, but drew on other published reports to consider what might happen in a 'worst case' scenario. It was assumed that no countermeasures were imposed to reduce people's exposure to radiation. Two examples are given, to illustrate the range of possible consequences:

- a crash with another train at an effective speed of 80 km/h, not involving a fire. WISE-Paris estimated that this would lead to a very local impact of a few tens of metres, with the maximum doses received not exceeding annual background rates.
- a crash with another train at an effective speed of 80 km/h, involving a fire lasting over 3½ hours leading to ignition of the zirconium cladding around the fuel. The WISE-Paris analysis predicts that such an event could have a regional impact affecting an area tens of kilometres wide.

Transport of spent nuclear fuel in the USA
Plans to move spent fuel from interim storage facilities across the country to a permanent disposal site at Yucca Mountain, Nevada in the USA have led to debate over security issues associated with future shipments of spent fuel. An analysis conducted by the Sandia National Laboratory in New Mexico for the US Department of Energy in 1999 investigated the effects of attacks on US spent fuel trucks and rail containers using two different types of weapons.[309] The study concluded that certain types of armour-piercing weapons could penetrate US spent fuel flasks – although only the outer wall of the spent fuel cask would be penetrated.

There is considerable dispute over whether breaching a spent fuel flask would cause a significant release of radioactive material. The Sandia study concluded that even in a worst case scenario, less than 1% of the spent fuel in a container would be released in the form of 'breathable' particles which people could inhale.[310] However, the study has been criticised by some stakeholders who believe the consequences of an attack could be much more severe than it states. A letter from the Governor of the State of Nevada to the US Nuclear Regulatory Commission (NRC) criticises, the reference weapons used in Sandia's analysis,[311] and the fact that all experimental data on flask response to weapons were taken from experiments conducted in the 1980s.[312] The NRC has recently commissioned Sandia to conduct a series of further assessments considering other modes of attack, including a) *a 20 passenger aircraft crashing into shipping containers b) sustained attack using a variety of weapons.*

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[307] WISE-Paris*, The Transports in the French Plutonium Industry*, commissioned by Greenpeace, February 2003.

[308] In France, spent fuel is held in wet-storage on reactor sites for several years before being transported off-site for reprocessing.

[309] R. Luna et al, Sandia National Laboratory, *Projected Source terms for Potential Sabotage Events related to Spent Fuel Shipments,* 1999, http://infoserve.sandia.gov/sand_doc/1999/990963.pdf. The study was based on computer simulations but drew on the results of earlier full scale tests.

[310] The health impacts of such a release were estimated to be 9 long term cancers for a rail container and 48 long term cancers for a truck against a backdrop of 1.1 million cancer deaths among the same population from other causes.

[311] The letter argues that *Sandia failed to consider weapons such as the TOW and Milan missiles which are capable of completely perforating rail as well as truck flasks.* See http://www.state.nv.us/nucwaste/news2000/nn10472.htm

[312] In addition, the authors of the Sandia paper point out in a subsequent publication that *producing a release from a spent fuel flask is a formidable task owing to the robust design necessitated by spent fuel containment and shielding requirements* and that there is incomplete understanding of how spent fuel behaves at very high temperatures, which limits the reliability of any predictions. See reference 208.

Box 10-5 Transport of spent nuclear fuel through London

Spent fuel from three nuclear power stations in the South East of England (Dungeness, Bradwell and Sizewell A) is transferred by rail to BNFL Sellafield for reprocessing (see Chapter 9). This is the responsibility of Direct Rail Services, a wholly owned subsidiary of BNFL.

The most direct route for transportation of this fuel is via London. Around three shipments pass through the capital every week. Trains are normally held at Willesden Brent Rail sidings for several hours. The transport of spent fuel complies with general operational safety requirements for rail transport (speed restrictions, etc) – there are no specific rules for spent fuel transport. There is a network rail code of practice which recommends ways to minimise hazards – for example, shipments of petrochemicals should be timed so as not to pass shipments of spent fuel. However, these are guidelines, rather than regulations. In practice, train schedules are subject to considerable variation and cannot always be accurately timed.

Concerns have been raised relating to both safety and security in recent years, by local interest groups and in an inquiry by the Greater London Authority (GLA) in 2001. [313]

Main issues

The GLA inquiry pointed out that spent fuel has been transported in the UK since 1962 and in that time no incidents involving release of radioactivity have occurred. Nevertheless, it noted that in the event of a serious release of radioactivity the consequences for Londoners would be severe. The following key issues were raised:

- security- the GLA inquiry raised concerns over trackside security at the time of the inquiry – including the need to keep people away from trains as well as *'the need to provide a first line of defence against terrorists seeking access to the flasks when a train is stopped in a marshalling yard'.* DRS have made a number of changes to security in the past three years (though not necessarily as a result of the GLA inquiry) but these arrangements are classified. OCNS recently reported that a no-notice spot check undertaken by OCNS transport security inspectors disclosed that *guarding arrangements were not being carried out satisfactorily* as a consequence of which DRS was instructed to cease marshalling at Willesden, although after one week matters had been rectified and activities recommenced.[314]
- routing- the GLA inquiry concluded that there was a need to examine alternative freight routes to transport spent nuclear fuel, bypassing London and other population centres. However, there is an inherent conflict in the requirements of European regulations, which stipulate both that shipments should avoid major population centres and should also take the most direct route available. DRS plan to announce any decisions on new transport routes once the defuelling of Bradwell power station is complete in 2005. No major changes will be made before then.
- emergency exercises- the inquiry highlighted a need for a RADSAFE exercise involving emergency services. Such an exercise was recently carried out.

Because the probability of occurrence of a release large enough to affect the public is considered extremely unlikely, current emergency planning arrangements do not need to incorporate provisions to protect the public along spent fuel transport routes (for example, provisions for evacuating or sheltering people). Chapter 11 discusses emergency planning arrangements in the event of a release of radioactive material during transport.

10.6 Transport of separated plutonium

Transport of separated plutonium may take place as part of the civilian nuclear power fuel cycle, or in small quantities for use in research establishments, or for military purposes. In the UK shipments have taken place for the following specific reasons:

- Military separated plutonium surplus to military requirements was transferred by road from Aldermaston to Sellafield in the 1990s. The MOD has now completed its planned shipments although it may decide to resume them in the future if there is a need.
- sea shipments of civilian separated plutonium from reprocessing from BNFL Sellafield to overseas customers (see 10.8)
- shipments between various military establishments.

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[313] Nuclear Waste Trains Investigative Committee, Greater London Authority, *Scrutiny of the transportation of nuclear waste by train through London,* October 2001.

[314] Office for Civil Nuclear Security, *The State of Security in the Civil Nuclear Industry*, April 2003 - March 2004.

There are currently no shipments of plutonium taking place for civilian purposes in the UK. However negotiations are under way for future transfers of plutonium between BNFL Sellafield and MOX plants in Europe.[315] The environmental group CORE (Cumbrians Opposed to a Radioactive Environment) anticipate that these shipments will raise concern about safety and security issues, particularly in Ireland and Scotland. The transport of plutonium (and MOX) is one of the issues under discussion by the Security Working Group within BNFL's stakeholder dialogue (see Box 6-3).

In France, frequent shipments of civilian plutonium take place, because plutonium produced at the Cap de la Hague reprocessing plant is sent to MOX fabrication facilities elsewhere in France and in Belgium. It is estimated that two shipments take place between La Hague and Marcoule every 7-10 days. The transport of separated plutonium in France generates considerable public concern: a recent report commissioned by Greenpeace states that *the transports routinely pass through Paris and Lyon* and *are vulnerable to both severe traffic accidents and deliberate attack*. [316]

Terrorist threat

Like spent fuel, plutonium is generally transported in 'Type B' containers, which are among the most robust in use for transport of radioactive material. Nevertheless, analysts suggest that some scenarios could subject the containers to more extreme conditions than they were designed to resist, leading to release of plutonium into the environment. [317]

The WISE-Paris analysis mentioned in the previous section discusses several scenarios involving road transport of separated plutonium in France. As with the spent fuel calculations, WISE-Paris did not carry out detailed technical analyses to estimate the amount of material released, but drew on other published reports to consider what might happen in a 'worst case' scenario. In both cases WISE-Paris assumed that no countermeasures were imposed to reduce people's exposure to radiation. This (i.e. POST's) report makes no comment on the likelihood of any of the scenarios – they are merely cited as examples to illustrate how the results of threat assessments can vary depending on the choice of scenario and on the assumptions made.

- a crash with another truck at an effective speed of 80 km/h: WISE-Paris postulates that ~5 mg of plutonium might be released (1/10000 of the contents of one box), with a very local impact over only a few tens of metres. Resulting radiation doses would be a few thousand times smaller than that from annual background radiation.
- a missile attack combined with a crash with a fuel tanker: in this extreme set of circumstances, WISE-Paris assume that 10% of the truck's entire contents might be released and predict that the plutonium would be deposited over an area 250 square kilometres wide. If *all* the plutonium were converted to breathable particles, hundreds of long term cancers could result. In practice, recorded accidents involving transport of plutonium have affected much smaller areas (see next section).

10.7 Transport of nuclear weapons

Nuclear weapons are transported under tight security and are designed with multiple safety systems to prevent unauthorised or accidental nuclear explosion. Such an explosion can occur only if the conventional chemical explosives used in nuclear weapons are detonated in a very

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[315] Cumbrians Opposed to a Radioactive Environment (CORE), *Sellafield Plutonium Shipments in the Offing,* 14th August 2003

[316] Large and Associates, *Potential Radiological Impact and Consequences arising from Incidents involving a Consignment of Plutonium from COGEMA/La Hague to Marcoule/Cadarache*, Commissioned by Greenpeace, March 2004.

[317] See 316 and 307.

precise manner, by the simultaneous initiation of a number of detonators with an electrical firing signal.

However, detonation of the conventional explosives used in nuclear weapons could in principle result in dispersal of radioactive material, as illustrated by some examples of accidents involving US nuclear weapons in the past. For example, according to published information, a US B-52 aircraft carrying four nuclear weapons collided with a tanker during refuelling and crashed in Palomares, Spain, in 1966. The high explosive component of the weapon detonated on impact[318] leading to dispersal of plutonium over 2.6 km^2 of land. Although the area affected was relatively small compared with the predictions mentioned in the previous section, decontamination took 800 US military personnel over 81 days and cost $650,000. 4600 drums of contaminated material were shipped back to the US for disposal.

UK nuclear weapons are only transported by road. Occasional movements of US nuclear weapons in the UK are conducted by air under stringent safety procedures.[319] In the case of both US and UK nuclear weapons, the Ministry of Defence state that inadvertent detonation of high explosives should not lead to a nuclear explosion and claim that '*there is a negligible explosive or radiological hazard from a nuclear weapon in all normal environments*'.[320]

10.8 Transport by sea[321]

The largest inventories of radioactive material transported by sea are those associated with the 'back end' of the nuclear fuel cycle. The following sea shipments take place or have taken place to/from the UK (to Sellafield) or France:

- Spent fuel is transported from Japan to Sellafield and Cap de la Hague. Since the 1960s, over 160 shipments have taken place involving over 1000 tonnes of spent fuel.
- Vitrified high level waste has been transported from France to Japan since 1995. As of May 2004, nine shipments have taken place.
- MOX sea shipments took place between Japan and Europe in 1999 (UK to Japan); 2001 (France to Japan) and 2002 (Japan to UK).[322] Further shipments are planned.[323]
- Sea shipments of separated civilian plutonium took place between Europe and Japan in 1984 and 1992. Further shipments are planned between the USA and Cherbourg, to be moved to Cadarache for processing into MOX test assemblies.[324]

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[318] This refers to detonation of the chemical explosives used in the weapons' construction and not to detonation of the weapon itself, which could result in a nuclear explosion.

[319] According to http://www.mod.uk/issues/laesi/section_a.htm

[320] According to http://www.mod.uk/issues/laesi/section_a.htm

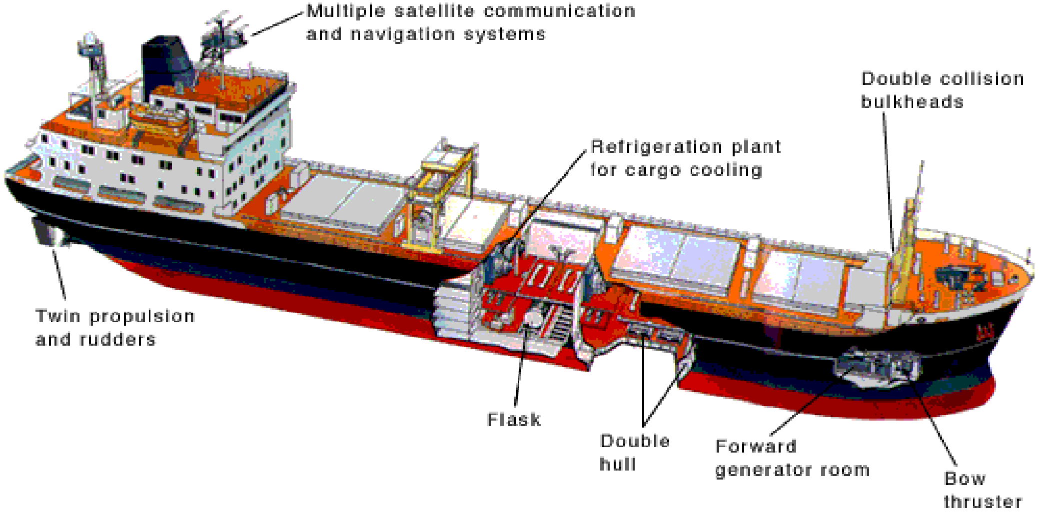
[321] British Nuclear Industry Forum, *Transport Matters,* October 2001.

[322] Return of MOX from Japan to UK following rejection by Japanese utilities.

[323] Office for Civil Nuclear Security, *The State of Security in the Civil Nuclear Industry*, April 2003-March 2004 para. 58

[324] Office for Civil Nuclear Security, *The State of Security in the Civil Nuclear Industry*, April 2003-March 2004 para. 59

Figure 10-3 Purpose built vessel for the transport of spent nuclear fuel.



Source: Uranium Information Centre (www.uic.au)

Shipments take place in purpose built ships owned by BNFL and Pacific Nuclear Transport Limited (PNTL), which is owned by BNFL, COGEMA and the Japanese utilities. Safety standards for transport of nuclear cargo are set by the International Maritime Organisation (IMO) in line with IAEA requirements. Materials are transported in type B flasks designed to withstand immersion under 200 metres of water for at least one hour. Ships have additional safety features such as double hulls to withstand collision damage, enhanced buoyancy and duplication of critical systems such as navigation and communications (see Figure 10-3). Details of security arrangements are not made public, although in the case of MOX shipments between the UK and Japan, OCNS states that the fuel was conveyed in PNTL ships which carried deck mounted naval guns and an armed escort provided by the UKAEA constabulary, and were escorted throughout the voyage by a second identical PNTL vessel.[325]

Concerns over the safety issues have been raised by some South American countries which lie along potential shipment routes, as well as by NGOs and the general public. The US Nuclear Control Institute has raised concerns that the fire and immersion requirements to which flasks are subjected are not stringent enough, in the light of accidents that are known to have occurred at sea.[326] Greenpeace have co-ordinated a number of protests in conjunction with sea shipments. There is evidence that public concern over sea shipments has increased in the past three years. An analysis of print media coverage of MOX shipments between the UK and Japan shows that the 2002 MOX shipment generated twice as many articles in the UK national media as the 1999 shipment, with increased focus on the threat of terrorist attacks (see Annex 9).

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[325] Office for Civil Nuclear Security, *The State of Security in the Civil Nuclear Industry*, October 2000 - March 2002.

[326] E. Lyman, Scientific Director, Nuclear Control Institute, *The Sea Shipment of Radioactive Materials: Safety and Environmental Concerns,* Presented to the conference on Carriage of Ultrahazardous Radioactive Cargo by Sea, Kuala Lumpur, Malaysia, 1999.

10.9 Limitations of public domain information

There is a considerable amount of information in the public domain about shipments of radioactive material. Because the container design used in transport in most countries complies with published international standards, it is possible to make deductions about the kinds of conditions containers could withstand. Design information can be obtained from some sources - the US GAO report on spent fuel includes diagrams of the various types of flask used in the USA.[327] UK authorities do not publish such detailed design information, but design has not changed substantially for several decades and technical information could probably be obtained from various sources. In addition, many NGOs publish information on transport routes via the internet.

However, detailed data on the response of containers to accidents or terrorist attacks are largely classified, as are detailed design specifications, and information on the way transports are carried out (e.g. information on security arrangements). A full analysis of the risks and consequences of a terrorist attack on a shipment of radioactive material could not be carried out without this information.

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[327] United States General Accounting Office, *Spent Nuclear Fuel: Options to Further Enhance Security,* July 2003.

11 Contingency Planning

11.1 Key points

- Emergency plans for deliberate releases of radioactive material from civilian nuclear sites would be based on plans for accidental releases. The Home Office would initially take the lead in co-ordinating the response at national level for an incident at a UK civil nuclear site (or during transport of materials for civilian purposes).
- Under the Radiation Emergency Preparedness and Public Information Regulations 2001 (REPPIR) the implementation of off-site emergency plans, and the provision of information to the public in the event of an emergency, is the responsibility of the local authority in which the nuclear site is located.
- A large range of organisations is involved in the preparation for and response to emergencies. This can cause confusion and lack of co-ordination, as reflected in practice exercises for radiological releases.
- The Civil Contingencies Bill aims to clarify the responsibilities of different agencies, to place statutory obligations on certain agencies at local level and to increase the effectiveness of emergency planning and response.
- There is some confusion over dose limits for emergency service personnel in emergency situations.
- The effectiveness of countermeasures will depend to a large extent on the co-operation of the general public in an emergency situation, which in turn depends on the effectiveness of measures taken to keep the public informed.
- Detailed emergency plans are in place for areas within a few kilometres of nuclear sites and could be extended to tens of kilometres if necessary. Some analysts believe the UK should strengthen arrangements for dealing with releases which could potentially affect wider areas.[328]

11.2 Introduction

This chapter discusses the UK's emergency arrangements for dealing with releases of radioactive material from nuclear facilities or during transport. In the event of a deliberate release, arrangements would be based on existing plans for accidental releases. These arrangements consist of five key stages, outlined in a document entitled *Dealing with Disaster* published by the Civil Contingencies Secretariat within the Cabinet Office (Box 11-5): [329]

- **risk assessment -** assessing the risk of an emergency situation arising
- **prevention -** taking measures to minimise this risk
- **preparation for emergency situations -** developing, reviewing and testing emergency plans
- **initial response to emergency situations -** this would primarily involve implementing countermeasures to protect the public
- **recovery phase -** taking actions necessary to return to normality following an emergency.

At each stage in emergency planning, arrangements are required on-site and at local, regional, national and international level.[330] [331] This chapter begins with an overview of the organisation of

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[328] Large and Associates, *Local Authority Emergency Planning in the locality of UK nuclear power plants,* 2002.

[329] Cabinet Office Civil Contingencies Secretariat, *Dealing with Disaster,* Revised 3rd edition, June 2003. See also *Dealing with Disasters Together*, a Scottish Executive publication which provides information on emergency planning in Scotland. These documents aim to provide the numerous agencies involved in emergency planning with guidelines on good practice.

[330] Health and Safety Executive , *Arrangements for Responding to Nuclear Emergencies,* 1994.

[331] Nuclear Emergency Planning Liaison Group (NEPLG), *Civil Nuclear Emergency Planning: Consolidated Guidance,* April 2003.

emergency management within government in section 11.3. It then discusses arrangements at each of these levels in turn in sections 11.4 to 11.8, considering the separate stages of preparation, initial response and recovery, where relevant. Although the focus of this chapter is releases from fixed installations, the same principles would broadly apply to releases during transport, discussed in section 11.9.

Key issues discussed in the course of this chapter include the UK's ability to respond to large scale radiological releases and the provision of information to the public. Some of these issues have been raised by NGOs and in official reports, including the House of Commons Defence Select Committee's report on *Defence and Security in the UK* in July 2002, commentary on the Civil Contingencies Bill (Box 11-5), and the House of Commons Science and Technology Select Committee's report on the *Scientific Response to Terrorism* in November 2003.

Box 11-1 CBRN emergency planning : who's who within government

The following government departments play a key role in responding to the threat of CBRN terrorism. See also Box 11-9, which lists Lead Government Departments for different emergency situations.

Cabinet Office
The Civil Contingencies Secretariat (CCS) within the Cabinet Office was set up in 2001, and aims to provide a central focus for the numerous agencies and departments involved in emergency planning in the UK. It was created in response to a succession of civil emergencies (e.g. the fuel crisis in 2000 and the foot and mouth crisis in 2001) and not specifically to deal with terrorist incidents.

Home Office
The Home Office is the lead department on CBRN issues and a CBRN unit within the Home Office was established in 2001. The police would be responsible for implementation of countermeasures in the event of any civil emergency involving threats to public security or public safety, including a CBRN attack.

Ministry of Defence (MoD)
The MoD has no direct role in responding to civil emergencies. However it might act in a supporting capacity – ranging from assisting civil authorities with restoring law and order in an emergency, to assisting the community at large (as seen during the floods of 2000). Such support would take place as part of the Military Assistance to Civil Authorities agreement (MACA).[332]

Office of Science and Technology (OST) within the Department of Trade and Industry (DTI)
OST is responsible for funding basic research and also supports the Chief Scientific Adviser (CSA) to the UK government. The CSA chairs the CBRN Science Working Group, set up to look at specific areas of CBRN resilience in 2001. In addition, the Scientific Advisory Panel for Emergency Response (SAPER) was set up by OST and the Cabinet Office in 2003, to provide additional scientific advice to government on CBRN countermeasures.[333]

Department of Health (DH)
The DH is responsible for national oversight and monitoring of public health in the event of a radiological emergency. It would provide advice to other government departments and to the NHS on the implications for public health of exposure to radiation. In addition, the Health Protection Agency provides specialist health emergency advice and support to government, NHS bodies and other stakeholders, and would play a key role in protecting public health in an emergency.[334]

The Office of the Deputy Prime Minister (ODPM)
ODPM plays a role in emergency planning, as it is responsible for policy on fire safety and the Fire and Rescue service, as well as on building regulations and related safety issues, and is also responsible for the network of Government Offices for the Regions.

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[332] Defence Select Committee, 6th report, session 2001-2002, *Defence and Security in the UK*, July 2002.

[333] House of Commons Science and Technology Committee, 8th report, Session 2002-2003, *The Scientific Response to Terrorism,* 20th October 2003.

[334] The HPA has a medical surveillance role through the Public Health Laboratory Service and a research function through the Health Protection Agency Porton Down (formerly the Centre for Microbiological Research).

11.3 Organisation of emergency management within government

There is no single national body responsible for disaster management in the UK. Several government departments are involved in responding to the threat of CBRN terrorism (Box 11-1). In the event of a CBRN attack, as with any civil national emergency, a 'Lead Government Department' or LGD would be convened to co-ordinate Central Government's response to the emergency. The LGD in charge would vary depending on the nature of the emergency. The role of the LGD is discussed in section 11.7. Each devolved administration (DA) has its own civil protection arrangements, which vary according to the terms of devolution settlements and local administrative arrangements. Further details of organisational structure are provided in Annex 8.

11.4 On-site emergency management

Preparation

On-site arrangements for responding to deliberate releases of radioactive material from a nuclear facility are based on existing emergency response plans for dealing with accidental releases, which would be adapted depending on the security situation in the event of an actual attack. These arrangements are tested in regular exercises (see Box 11-2). UK civil nuclear sites are in the process of making additional provisions for dealing with emergency situations. The 'Vital Areas Study' mentioned in section 6.4 aims to look more closely at the response of specific facilities to acts of sabotage and to identify any changes required to strengthen arrangements.

Initial Response

In the event of either an accidental or deliberate release, operator duties would include:

- **minimising the extent of the release** - actions would follow established guidelines for restoring sites to a safe condition after an accident. All site operators maintain such guidelines as part of the licensing procedure. These include generic (non-site-specific) guidelines for severe accidents, which are regarded as unlikely but could potentially give rise to large releases of radioactive material.
- **providing information to relevant external organisations -** (e.g. local authorities and the public - Box 11-4). There are two categories of emergency situation. The first is 'site emergency', where the effects are confined within the site boundary. The second is 'nuclear emergency' where countermeasures might be needed to protect the public outside the site security fence. Provision of information would mainly be relevant for events in the second category.
- **monitoring levels of radioactivity on-site and around the site -** the site operator would be responsible for monitoring levels of radioactivity on-site and in the local area. The area around the site covered by the monitoring team varies between ~15-40 km depending on the facility. The RIMNET[335] national monitoring network would provide some information on a national scale for larger releases although it was originally set up to monitor levels of radioactivity generated by overseas incidents (see section 11.8).

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[335] Radiation Monitoring and Nuclear Emergency Response System.

Box 11-2 Emergency exercises

Two different types of emergency exercises currently take place at nuclear facilities in the UK: exercises designed to test response to terrorist attacks, and those that test arrangements for accidents. In the case of accidents, different categories of exercise are designed to test arrangements at different levels (i.e. on-site, local and national level).

Emergency exercises for deliberate attacks
The Home Office oversees national counter-terrorist exercises which are reported to take place regularly.[336] Some are practical and some are 'desk-top' exercises. These exercises address a range of terrorist threats – previous ones have involved testing response to hijacked aircraft and nuclear devices. For security reasons, the details and results of such exercises are classified. OCNS oversees security-related exercises at nuclear plants, as discussed in Chapter 6.

Emergency exercises for accidental releases
Emergency arrangements for accidental releases of radioactive material, which would also be activated in the event of a deliberate release, are regularly tested to check their effectiveness. Exercises take place on three different levels around licensed nuclear sites:

- **Level 1** (once a year at each site) - these test the performance of the operator on- and off-site in an accident situation. They often involve emergency services and local external organisations and are monitored by the nuclear safety regulator. They can involve practical simulation of the emergency situation.
- **Level 2** (once every three years at each site) - these test off-site arrangements and the operation of the off-site facility (see section 11.5). As well as involving the site operators, emergency services and other local organisations, they have input from government departments (as well as the relevant departments within the devolved administrations – see Annex 8) and other national bodies.
- **Level 3** - every year one of the level 2 exercises is upgraded to test arrangements at national level. This involves testing the performance of the Nuclear Emergency Briefing Room (see section 11.7). They also evaluate communication between local and national agencies. For exercises within the Devolved Administrations (DA), a lead department within the DA would be normally responsible for co-ordinating the exercise.

Members of the public are not directly involved in most exercises, although in some cases communications links with specific institutions such as schools and hospitals, are tested.

Recent exercises
The largest scale exercise held in recent years was operation 'ISIS' in May 2002. This involved simulation of a major event at Bradwell Power Station, affecting a radius of 40 km around the site. An exercise of this scale takes place roughly once in five years. The final report on ISIS described the exercise as a successful demonstration of the ability to extend existing detailed emergency arrangements. However some areas for improvement were identified, including:[337]

- the quality and supply of monitoring information – for example there was not enough information made available initially about the nature of the release to take decisions on water management strategies.
- notification procedures - for example some agencies were initially confused about which station the incident had occurred at, because sites other than Bradwell were sending out notifications.
- a need to improve cross county liaisons between county councils and police forces was identified.
- provision of information to the public – the public were told by the police to listen to the TV and radio, but one agency commented that *there was no proactive response to public concern.*

Concerns were also expressed over the practical implementation of countermeasures - for example, iodine tablets were not made available until 8 hours after the start of the release.

Permitted radiation doses

In the event of a radiological emergency at a nuclear site, workers on-site and emergency response workers might be exposed to higher levels of radiation than are permitted during normal operations (see Box 11-3), depending on the circumstances. There is no single guidance document explaining what the legal dose limits are for workers in emergency situations in the UK. The limits are set by individual employers on a case–by-case basis and are set out in off-site emergency plans for specific nuclear sites.

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[336] http://www.homeoffice.gov.uk/terrorism/govprotect/resilience/counterterr.html#types%20of%20exercise

[337] Emergency Planning Services, BNFL Magnox Generation, Bradwell Level 3 Extendibility Exercise, 10th May 2002.

Box 11-3 Dose limits for workers

'Planned' releases.
Legal dose limits for planned releases (i.e. releases during normal operating conditions) are set by the Health and Safety Executive under the Ionising Radiation Regulations Act (IRR), 1999. Under the IRR 1999, the maximum permissible radiation dose that a member of the public may receive due to *planned* releases of radioactive material is fixed at 1mSv per year. This limit has been determined by the NRPB based on international limits set by the ICRP (see Annex 5). It does not take into account unplanned exposure (i.e. due to accidents or deliberate acts) or background radiation. Legal dose limits for people that might be exposed to radiation as a result of their occupation (this includes the emergency services) are higher – as of July 2004 an average yearly limit of 20 mSv.

Unplanned releases (i.e. accidents or deliberate attacks resulting in release of radioactivity)
Under the REPPIR regulations (Box 11-4) the dose limits for workers specified in IRR 1999 may be overridden in the event of an accidental release of radioactive material - thus workers would be legally permitted to receive higher radiation doses than those specified in IRR 1999. The NII states that although REPPIR (Box 11-4) does not specifically apply to deliberate acts, it provides an adequate working framework for any such events. Recommended dose limits in emergencies are specified in IAEA guidance and fall between 100 mSv and 500 mSv depending on the circumstances (see section 11.4)

Thus, different organisations involved in emergency response have different policies on the doses that their staff would be permitted to receive in an emergency. For example, the Chief Fire Officers Association are drafting guidance confirming previous UK guidance that Fire Officers could receive up to 100mSv radiation dose for the purpose of life saving. Conversely, police forces in some areas would plan not to enter hazardous zones in emergency situations, based on their interpretation of permitted dose limits. There is also concern amongst some local authority workers about whether or not they are classified as 'intervention workers' and would be required to enter these zones.[338]

11.5 Off-site emergency management - local level

If a release from a nuclear facility had off-site consequences, the first response would take place at local level. The main concern would be to protect the public from excess exposure to radiation by implementing countermeasures which might include evacuation or sheltering, restriction of food and water supplies or issuing iodine tablets.[339]

A wide range of agencies would be involved:

- **local authorities** - since the introduction of the 2001 REPPIR regulations Box 11-4, local authorities have overall responsibility for preparing, testing and implementing off-site emergency plans and for keeping the public informed, as well as for overseeing recovery operations following a release (see Box 11-4).[340]
- **police** - although local authorities are responsible for drawing up emergency plans, it would be the police who actually implement them in the event of a release. They would decide what countermeasures should be taken, based on advice from the Government Technical Adviser[341].
- **fire services -** would be responsible for fire fighting and rescue operations on-site and in the area around the site if necessary. They are also equipped to undertake mass decontamination

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[338] See *Nuclear Accidents in Australia*, Jean McSorley, Greenpeace Australia/Pacific, 2002. This paper raises concerns that workers may not be sufficiently informed in advance of the risks associated with ionising radiation.

[339] Health and Safety Executive, *Arrangements for Responding to Nuclear Emergencies,* 1994.

[340] See Home Office, *The Release of CBRN Substances or Material: Guidance for Local Authorities,* August 2003. This is guidance issued by the Home Office which provides generic advice for local authorities on actions to be taken in the event of a CBRN attack: It highlights aspects of emergency preparedness which should be considered by local authorities. Radiological releases are discussed in the context of 'dirty bomb attacks' – the document does not specifically refer to the threat of sabotage of nuclear installations.

[341] The Government Technical Advisor who would be selected from one of Her Majesty's Deputy Chief Nuclear Inspectors.

of people, in support of the health authorities.

- **health authorities -** responsible for the provision of medical advice and support both in the preparation for and in response to radiological emergencies. Specific roles would include drawing up plans for the issue of iodine tablets and monitoring people's exposure to radiation.
- **ambulance services** - would assist the public where necessary and treat casualties both on-site and off-site.
- **water providers** - would be responsible for restricting water supplies, if necessary.

Advice would also be provided by national organisations including the Environment Agency (or the Scottish Environment Protection Agency in Scotland), the NRPB, the Health Protection Agency, the Food Standards Agency and the NII. As an efficient emergency response relies on the co-ordination of so many organisations, there is a Nuclear Emergency Planning Liaison Group (NEPLG) within the DTI, which aims to bring together different groups with interests in off-site civil nuclear emergency planning.

The large range of organisations involved in the preparation for and response to emergencies has sometimes led to confusion over responsibilities (reflected in practice exercises for radiological releases) and a lack of co-ordination. The Civil Contingencies Bill (Box 11-5) aims to clarify the responsibilities of different agencies.

Preparedness

Arrangements for dealing with off-site releases of radioactive material at local level are regularly tested. The most recent large scale exercise in the UK was 'ISIS' in May 2002 (Box 11-2).[342] Below, some key issues are discussed, such as the UK's preparedness for large scale releases of radioactive material, the provision of advance information to the public and the preparedness of the corporate sector.

Box 11-4 Radiation Emergency Preparedness and Public Information Regulations

The Radiation Emergency Preparedness and Public Information Regulations (REPPIR) regulations came into force in September 2001. REPPIR replaced the Public Information for Radiation Emergencies 1992 (PIRER) regulations and set out the responsibilities of nuclear operators, carriers of radioactive material, local authorities, and employers of people working with ionising radiation, in the event of a radiological emergency. Until the introduction of REPPIR offsite nuclear emergency planning was carried out on a voluntary basis, coordinated by the DTI. REPPIR introduced provisions for involved agencies to charge the operators for their services.

Under REPPIR, nuclear operators and carriers of radioactive material are required to provide information to the public in advance, about what to do in the event of an emergency. However local authorities are responsible for keeping the public informed in the event of an emergency actually occurring .[343]

REPPIR makes no reference to acts of sabotage, but its provisions for accidental releases would offer a framework for responding to releases caused by terrorist attack.

REPPIR regulations do not apply to type B and type C packages, which means that materials such as spent fuel, which in most cases are type 'B' packages, are not covered by REPPIR. Emergencies during transport of spent fuel would be covered under RADSAFE arrangements (see section 11.9).

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[342] Emergency Planning Services, BNFL Magnox Generation, Bradwell Level 3 Extendibility Exercise, 10th May 2002

[343] www.hse-databases.co.uk/spd/spdemp.htm

Box 11-5 The Civil Contingencies Bill

Background

In January 2004 the government introduced the Civil Contingencies Bill in the House of Commons. It aims to modernise UK legislation on emergency planning. Existing legislation is based on the Civil Defence Act 1948 and the Emergency Powers Act 1920 and was not designed to cope with large-scale terrorist attacks. It consists of two main parts: civil protection and emergency powers:

Part 1: Civil protection

The Bill imposes statutory obligations on local organisations which already play a vital role in emergency planning arrangements, but which until now have acted without legislation setting out their responsibilities.

- It assigns 'Category 1' organisations (e.g. local authorities, emergency services) with duties involving the assessment of, prevention of, and planning for, emergency situations.[344] They must also provide assistance to businesses, particularly to enable continued provision of services that may need to be delivered in an emergency. 'Category 2' organisations (e.g. utilities) will also have duties.
- 'Local resilience forums' will be created to strengthen links between these different organisations.
- The new legislation will build on existing plans to establish a new tier of civil protection at regional level. However the Bill does not impose statutory obligations at a regional or national level.

Part 2: Increasing emergency powers

The Bill broadens the definition of emergency situations to include events that pose threats to the security of a place in the UK, such as terrorism, as well as events that could cause serious damage to human welfare in a place in the UK, such as natural disasters like flooding. The Bill allows for emergency powers to have effect in only a part of the UK rather than the whole country.

Issues arising:

Although most commentary on the Bill is broadly in support of its intentions, some specific issues have arisen both after publication of the Draft Bill in July 2003, and during progress of the Bill through Parliament:[345]

- **human rights** - after the publication of the Draft Bill, part 2 proved to be the most contentious. Concerns about the potential for emergency regulations to infringe human rights laws were raised by several parliamentary committees and external groups.[346] [347] [348] To address these issues, the government made significant amendments to the Bill,[349] although some concerns remain.[350]
- **funding** - resources available to local authorities for emergency planning currently come from the ring-fenced Civil Defence grant, which is £19 million each year. There are concerns that funding will be inadequate to cover expenditure under the new Act.[351] The Local Government Association (LGA) points out that the Civil Defence Grant is already insufficient to meet current expenditure and that in future, such funding will not be ring-fenced; also that public expectations of emergency services have increased in recent years . [352] [353] [354]
- **statutory obligations** - the Bill places statutory obligations on local organisations, but none at regional or national level. The LGA believes this could lead to confusion over roles and responsibilities at different levels.
- **draft regulations** - concerns were raised that the absence of draft regulations in the Bill makes it difficult for local authorities to estimate the cost of their new responsibilities.[355]

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[344] Note that local authorities will not be involved in any way in assessing the risk of a deliberate attack on a nuclear facility – this remains a national-level responsibility undertaken by OCNS on behalf of the Secretary of State.

[345] The Civil Contingencies Bill had its Report stage in the House of Commons on 24th May 2004, and passed to the House of Lords on 25th May. The main changes made after Report stage relate to cross-border co-operation and information sharing between emergency responders in Scotland and the rest of the UK

[346] Joint Committee on the Draft Civil Contingencies Bill, First Report, Session 2002-2003, November 2003.

[347] House of Commons Defence Select Committee, 7th report, session 2002-2003*,* July 2003.

[348] Joint Committee on Human Rights, Session 2002 - 2003, Report on the Draft Civil Contingencies Bill*,* June 2003.

[349] See *The Government's Response to the Report of the Joint Committee on the Draft Civil Contingencies Bill*, *Incorporating The government's Response to the Report of the House of Commons Defence Committee,* Cabinet Office, January *2004*. (paragraph 29).

[350] Liberty, *Response to the government's Civil Contingencies Bill,* Press Release, January 2004.

[351] House of Commons *Hansard*, 19th January 2004, col. 1128.

[352] The LGA was formed on 1st April 1997, and represents the local authorities of England and Wales.

[353] Local Government Association, *Final Report on the draft Civil Contingencies Bill*, September 2003.

[354] Emergency Planning Society*, Response of the Emergency Planning Society to the Draft Civil Contingencies Bill*, September 2003.

[355] Note however that a draft set of regulations was published alongside the Bill, for illustrative purposes.

Large scale releases

For the purposes of off-site emergency planning, a designated zone exists around all nuclear facilities, within which detailed arrangements for implementation of countermeasures are in place. The size of this zone (known as the Detailed Emergency Planning Zone or DEPZ) depends on the facility, but usually extends to a radius of between 1 and 3 km around the facility. Pre-distribution of iodine tablets already occurs within the DEPZ around some UK nuclear power plants, and there are plans to pre-distribute at some others, although this is not yet general policy. These detailed zones are designed to be 'extendable' to up to 10-15km if necessary.[356] Thus, off-site emergency plans are designed to cope with accidents that are considered 'unlikely', although they are not designed to deal with 'worst-case' scenarios, which could potentially affect much wider areas (as outlined in Chapters 8 and 9).

The ability of current emergency plans to cope with large-scale releases is a key issue of public interest, particularly in the light of increased concern over the terrorist threat. A study commissioned by Greenpeace in 2002 noted that '*At the local level the REPPIR off-site plans cater for relatively small scale and 'manageable' incidents and give no specific regard to acts of terrorism, other than to claim that the plans can be extended to cope*'. [357] According to the LGA, although all local authorities are advised to have plans in place to deal with radiological emergencies, in practice those that do not host a nuclear site are not well prepared for such situations.

There is a limit to how far emergency plans can be extended. For example, evacuation would pose considerable logistical challenges - factors to consider include warning the public, providing transport and drivers, and availability of accommodation for evacuated residents. Thus, it would be almost impossible to evacuate entire cities. The effectiveness of countermeasures would also depend on the reaction of the general public, especially the extent to which they co-operated with official instructions in an emergency situation.

Many local authorities would rely on private companies to supply various services in the event of any emergency. However, many have placed contracts with the same companies, which may not have the resources to cope with a large-scale release. In addition, concerns have been raised about the adequacy of funding available to local authorities to respond to emergencies (see Box 11-5 on the Civil Contingencies Bill).

Provision of information to the public in advance

The effectiveness of emergency plans in an emergency situation will depend on the co-operation of the general public, which in turn depends on the measures taken to keep the public informed. Most local authorities place copies of emergency plans in local libraries, although they are advised to restrict the information in them for security reasons. Some local authorities also distribute leaflets to people within the Detailed Emergency Planning Zone. For example, the Cumbrian local authority distributes leaflets to all residents within 2km of Sellafield and places information in local schools. Information can also be obtained from various central government web sites such as that of the Civil Contingencies Secretariat.[358]

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[356] The number of people living within these zones varies considerably depending on the facility. Sellafield, for example has ~40 residents living within the detailed emergency planning zone of 2km, and ~6700 living within the extended zone of 6km. In comparison, nuclear plants such as Heysham are very close to major towns, and tens of thousands of people might live within a few kilometres.

[357] Large and Associates, *Local Authority Emergency Planning in the locality of UK nuclear power plants,* 2002.

[358] See www.ukresilience.info

However, the National Steering Committee on Warning and Informing the Public (NSCWIP – see Box 11-7) believes that a nationwide public education programme is necessary to improve UK resilience to emergency situations. The committee has initiated a number of public education schemes, such as the production of a national video 'Go in, stay in, tune in' designed to raise the public's awareness of the importance of shelter in the event of an emergency. In addition, the BBC and the NSCWIP have initiated the 'Connecting in a Crisis' scheme which is designed to help broadcasters and emergency planners work together to communicate with the public.

The House of Commons Science and Technology Committee's report on *The Scientific Response to Terrorism* raised concerns over the limited amount of information being provided by government to the public on CBRN issues, stating that *a clear picture which would provide the necessary reassurance to the public has not yet emerged* and also that *the public is insufficiently prepared for a CBRN attack and hence the country (which needs an informed public) is also insufficiently prepared.*[359]

In Ireland, generic information on countermeasures that might be implemented in the event of a radiological emergency has been summarised in a leaflet and distributed to all households. Ireland has no nuclear plants but has emergency planning arrangements in place for radiological releases,[360] focussing primarily on the possibility of a release from a UK facility, although the plans would be applicable in the event of a release from any overseas location.

Corporate sector

The corporate sector could also be highly vulnerable to acts of terrorism. A survey undertaken by the security company mi2g in 2003 (see Box 11-6) showed that only half of participants considered themselves to be 'well prepared' for CBRN-D (chemical, biological, radiological, nuclear or digital) terrorism. It also found that '*many decision makers are not planning to do anything about this issue because they feel that either September 11th was a one off or that the government will step in immediately if a major incident takes place*'.[361]

Box 11-6 Survey of corporate sector preparedness for acts of terrorism

In 2003, the corporate security advisers mi2g undertook a survey of decision makers with 40 businesses (across the whole of the commercial sector), both in the UK and in the USA, to investigate preparedness for CBRN-D terrorism. It found that although half of the participants '*perceive their organisations to be well prepared for CBRN-D type threats*' many were relatively unprepared. For example:

- one in five organisations did not have the capability to inform staff worldwide of the occurrence of a major disaster and could not identify precisely where staff and key assets were at any one time.
- one in three could not make arrangements for a backup supplier to continue their business.
- one in three did not have designated staff for disaster recovery, and had not made arrangements for insurance cover in the event of a CBRN-D disaster.

Under new legislation set out in the Civil Contingencies Bill (Box 11-5) local authorities would be responsible for assisting businesses to provide continued services in the event of an emergency. The House of Commons Science & Technology Committee's report mentioned earlier

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[359] Note that in its response to the committee's report, the government states that it '*rejects the criticisms within the report that suggest the government is being less open than it need be or that fear of alarming the public is slowing down the drive to increase protection'.* See *The government Reply to the Eighth Report from the House of Commons Science and Technology Select Committee*, Session 2002-2003.

[360] The Irish National Emergency Plan for Nuclear Accidents was developed following the Chernobyl accident in 1986.

[361] Mi2g, *How prepared is the corporate sector for terrorism?* News Alert, May 2003.

recommends that government provide detailed guidance to companies on CBRN countermeasures, complemented with a system of fiscal incentives or grants to offset the cost.[362]

Initial Response to off-site emergencies

For larger civil installations, off-site facilities at some distance from nuclear sites have been established by the nuclear operators, from which the emergency response would be co-ordinated and arrangements could be made to brief the media and the general public.

Some issues arise in relation to the initial off-site response to emergency situations, such as the resources available to local agencies to respond to CBRN incidents, how the public would be kept informed and how the agencies involved would communicate with each other. These are discussed below.

Resources

fire services - The Fire and Rescue service, [363] in partnership with the Department of Health, is responsible for the management of public mass decontamination in the event of radiological, biological or chemical attack. In 2002, the House of Commons Defence Select Committee raised concerns about the resources available to the fire and ambulance services to respond to radiological emergencies.[364] However, several new initiatives are now underway under ODPM's 'New Dimension' programme. Additional decontamination equipment is being distributed to fire services across the country, and ODPM is jointly funding research into the decontamination of people and the design of protective equipment. [365]

training - In recent years, measures have been taken to increase the ability of the local agencies mentioned above to respond to CBRN incidents. For example, it is now a national requirement that a minimum of 5% of staff within every police force should have specialist training to deal with such incidents.

Public warning

In an emergency situation, warning systems such as sirens, or TV and radio bulletins, would be a used to communicate with the public. Such systems are particularly important because the police, who are in charge of implementing emergency plans, might decide not to enter emergency zones due to concerns over radiation exposure (see section 11.4 on dose levels).

The National Steering Committee on Warning and Informing the Public (NSCWIP) believes that more use could be made of modern technologies (e.g. SMS messages on mobile phones) in warning the public. It has raised a number of concerns about arrangements in the UK, and is involved in various initiatives to improve the situation (see Box 11-7).

Emergency communications networks

The Cabinet Office's Emergency Communications Network (ECN) provides links between local authorities, emergency services and a number of central government departments.[366] The House of Commons Defence Select Committee has raised concerns over the reliability of the ECN.[367]

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[362] House of Commons Science and Technology Committee, 8th report, Session 2002-2003, *The Scientific Response to Terrorism,* 20th October 2003.

[363] Policy on the Fire and Rescue service is the responsibility of the Office of the Deputy Prime Minister (ODPM).

[364] Defence Select Committee, 6th report, session 2001-2002, *Defence and Security in the UK*, July 2002.

[365] See reference 362.

[366] Cabinet Office Civil Contingencies Secretariat, *Dealing with Disaster,* Revised 3rd edition, June 2003.

[367] Defence Select Committee, 6th report, session 2001-2002, *Defence and Security in the UK*, July 2002.

Box 11-7 The National Steering Committee on Warning and Informing the Public

The NSCWIP was set up in 1995 and is dedicated to encouraging improvements in the arrangements for warning the public of an imminent or actual threat to life, and advising them of appropriate action to take. The committee believe that several issues require further attention at national level, including:

- lack of clear statutory responsibilities for warning the public during many types of incidents. Negotiations with government are currently under way, to clarify these responsibilities, and to incorporate them into secondary legislation relating to the Civil Contingencies Bill (Box 11-5).
- lack of a national culture of awareness amongst the public of how to respond to large-scale emergencies (see next section).
- the ability to warn both a static and transient population at all times of day and night.
- the need to influence development of information and communication technology so that it can be more effectively used to warn and inform members of the public. For example, NSCWIP have facilitated the creation of an emergency warning page on CEEFAX. They also believe more use could be made of SMS messaging via mobile phones to warn the public.

Currently, the network is voice-based, and does not enable information to be transmitted electronically (i.e. via e-mail), which would be one of the most effective ways of exchanging detailed information in an emergency situation. A complete review of the existing system is currently under way and alternative options are being examined. Major changes are not likely to be made before November 2005, when the current contract expires.

Recovery following a release of radioactive material

The return to normality after a release would involve many factors, for example facilitating people's return to their homes, environmental clean-up activities such as decontaminating land and buildings, and managing any radioactive waste. The local authority would be responsible for leading recovery operations, with advice from DEFRA, the NRPB, the environment agencies and other technical centres. These agencies would also act to ensure that the strategies employed during the initial emergency period did not create unnecessary problems later - for example the generation of radioactive waste, which would have to be managed during the recovery phase.

Off-site emergency plans currently focus largely on the initial response to an event rather than on the recovery phase. However, several government departments and advisory bodies are currently collaborating to improve the information available on recovery management. In March 2004, DEFRA published a guidance document to help local authorities and other involved organisations to develop practical recovery strategies. The guidelines identify the following priority actions for recovery:

- stabilising any further migration of contamination by establishing a physical cordon around the affected area, where possible (although there may not always be a well-defined boundary)
- surveying the affected area - i.e. environmental monitoring to map affected areas and provide a basis for strategies for the decontamination and restoration of the environment.
- deciding on target clearance levels - i.e. deciding *what level of residual contamination may safely be permitted to remain* based on knowledge of risks to public health from the substance in question[368]
- developing phased recovery options - the recovery process would probably require a phased approach with different remedial actions carried out in sequence. Box 11-8 outlines some common decontamination strategies. Decontamination is not a straightforward exercise. Even where suitable techniques have been identified for particular purposes, they may not be

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[368] The guidelines state that while such standards are well understood for radiological substances, *there remain a number of technical uncertainties when applying military decontamination data to civilian clean up scenarios*. To assist in the decision making process, the NRPB, sponsored by various government departments, is developing a handbook for local authority use, which compiles radiological safety data and gives practical advice on management processes and methods of recovery from radiological incidents.

widely available, or they may be too expensive to implement on a large scale.
- transport and disposal of wastes - large volumes of radioactive waste might be generated through decontamination. The guidelines state that *the success of the recovery option would depend on the availability of disposal routes for these wastes and on the receiving capacity of the disposal location.*[369]

Response to the above guidelines has been positive, although concerns have been raised about the adequacy of the funding available to local authorities.

11.6 Regional level

The government is currently implementing new measures to strengthen response at a regional level. The main role of the regional tier in emergency management is to assist in planning of the emergency response, to improve its co-ordination, and to assist in recovery. Regional Resilience Forums have already been formed to bring together stakeholders such as central government agencies, the armed forces, and representatives of local responders such as the emergency services and local authorities. The Civil Contingencies Bill makes additional provisions for arrangements at a regional level although these are non-statutory. However, several commentators believe the role of regional response organisations needs to be clarified.[370]

11.7 National level response

Preparation

Research into CBRN countermeasures

The importance of harnessing science and technology to develop countermeasures to CBRN terrorism was highlighted in the House of Commons Science and Technology Committee's 2003 report on *The Scientific Response to Terrorism.* This discussed the organisation of research into CBRN countermeasures within government and identified a number of government departments undertaking research into CBRN countermeasures.[371] However it raised concerns about long term research and development into CBRN countermeasures, pointing out that the UK's main source of expertise, the Defence Science and Technology Laboratory (Dstl) at Porton Down, has a military focus and does not have a home defence remit. The report also identified '*a weak scientific culture within the Home Office'*, the lead government department on CBRN issues. Changes made to improve this situation include the appointment of a Chief Scientific Adviser within the Home Office. The Committee proposed the creation of a Centre for Home Defence, which would act as a focal point for scientific and technological research into CBRN countermeasures, although the government rejected this.[372]

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[369] The local authority might need to provide interim storage facilities for solid waste - the guidelines suggest options such as *temporary storage of hazardous wastes in ISO containers at a military site or a sport stadium.*

[370] See for example Local Government Association, *Final Report on the draft Civil Contingencies Bill*, September 2003.

[371] Including the Ministry of Defence, the Home Office, the Department of Health (including the Health Protection Agency), and the Office of the Deputy Prime Minister (ODPM).

[372] In its response, the government stated that '*although the creation of a Centre for Home Defence could have some advantages*' the creation of a new government agency would not be the most effective way to strengthen civil research into CBRN issues, as it would be expensive and time consuming and would involve restructuring existing programmes. See *The government Reply to the Eighth Report from the House of Commons Science and Technology Select Committee*, Session 2002-2003.

Box 11-8 Environmental decontamination and clean-up following radiological releases

Research into radiological decontamination techniques has been under way since the 1950s, when efforts focussed on recovery operations following a nuclear attack. In addition, extensive research has been carried out since the Chernobyl accident. Some examples of available techniques are listed below. The choice of technique would depend on the area of land affected and its use, as well as the nature of the release, and would also have to consider:

- Efficiency - the factor by which contamination levels would be reduced.
- Any resuspension of radioactive material caused by the activity.
- Doses to workers.
- The amount of any radioactive waste generated and its physical form.
- the cost of implementing the technique and the availability of resources to carry it out.

Examples of decontamination techniques in agricultural areas include:

- mechanical techniques: these range from removing vegetation and soil to ploughing land to reduce levels of radioactivity in the surface layer. The NRPB identified the technique of 'skim and burial ploughing' where the surface layer is removed and then buried at a depth of half a metre, as being highly effective on UK arable land in the event of a release of a fissile material such as caesium-137 although the equipment for implementing this is not widely available in the UK.
- chemical techniques - adding chemicals to the soil to prevent uptake of radioactive materials by vegetation. After Chernobyl, many countries in the FSU added potassium fertiliser to reduce the uptake of radioactive caesium by plants. However the NRPB has concluded that such techniques would be less effective in the UK where soil is more fertile.
- changes in land use - in principle changes could be made to the type of crops grown on affected agricultural land. However research has shown that this option would be of limited effectiveness in the UK .
- changes in animal feeding regimes - levels of radioactivity in animal produce can be reduced by supplying livestock with unaffected feed, or if this is not possible, by administering chemical binders known as AFCF[373] to livestock (e.g. by adding it to feed). This has been permitted in the UK since 2001 and so could be used in a nuclear emergency. AFCF was not used in the UK following the Chernobyl accident, but was used in Norway on reindeer. A similar compound was also used in parts of the Former Soviet Union (FSU).

Examples of decontamination techniques in urban areas include:

- buildings – in general, decontamination of the walls of buildings is unlikely to be very effective in reducing exposures as relatively little contamination adheres to them compared with horizontal surfaces. Firehosing was used to obtain dose reductions from the outside of buildings following Chernobyl, although the waste water generated was found to be a problem. Sandblasting of walls can also be carried out although this is destructive and may need to be followed by resurfacing. Polymer coatings have also been developed which can be applied and peeled off – they generate minimum waste and are not destructive. However, they are more costly and would be impractical to use over large areas.
- Roads - doses can be reduced by resurfacing of roads, which will also prevent natural weathering from causing resuspension of radioactive material. Other options include firehosing (see above) and vacuum sweeping.
- grass and soil - doses can be reduced by removal of soil and turf, as well as by grass cutting and tree felling. Soil removal was used extensively in the FSU after the Chernobyl accident.

Principal Source: Review of decontamination and clean-up techniques for use in the UK following accidental releases to the environment. NRPB-R288, 1996.

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[373] ammonium hexacyanoferrate.

Initial response

In the event of any civil national emergency, the Civil Contingencies Committee (CCC) would be convened to oversee the response, although it would not actually be in charge of implementation. It would allocate responsibility to a Lead Government Department (LGD) whose role would be to co-ordinate central government response to the emergency, as well as to disseminate information to the media and the general public, and to provide specialist advice to local agencies. The LGD in charge would vary depending on the nature of the emergency (see below).

The LGD would be responsible for setting up a Nuclear Emergency Briefing Room in London, which would be Whitehall's main point of contact with the local response. This would be staffed with advisers from a range of government departments as well as experts from the regulators and advisory bodies. It would also be the focal point within central government for briefing the media and the general public.

There are some concerns that having different LGDs for different types of emergency causes confusion over the responsibilities of different government departments in non-government agencies.[374] The structure of LGDs has however been maintained in the Civil Contingencies Bill, with various provisions to improve co-ordination between national and local level.

Responsibilities of the devolved administrations

Terrorism is a reserved issue, therefore UK central government would be in charge of co-ordinating the response to a terrorist incident within the area of a devolved administration. The devolved administrations would be represented on the Civil Contingencies Committee. For example, if an event affected both England and Scotland, then both the DTI and First Minister for Scotland would be represented. Management of the consequences of the event would fall largely to the devolved administration itself. The arrangements and responsibilities of the devolved administrations vary according to the terms of devolution settlements and local administrative arrangements. Further details on organisational structure are provided in Annex 8.

Box 11-9 Lead Government Departments

The choice of Lead Government Department (LGD) in charge of the national response to a deliberate attack on a nuclear facility would vary depending on the nature of the event, as listed below. For an incident at a civil nuclear site in the UK, responsibility during the counter terrorist phase would fall to the Home Office Terrorism and Protection Unit and longer term responsibility would then be transferred to the appropriate LGD.[375]

- civil site in the England and Wales - longer term responsibility for consequence management would rest with the Department of Trade and Industry (DTI).
- civil nuclear site in Scotland - responsibilities would fall to the Scottish Executive. DTI would still be responsible for briefing the Westminster Parliament and the UK's international partners.
- land transport for civilian purposes in England, Scotland or Wales - longer term responsibility for consequence management would fall to the Department for Transport (DfT).
- military site in the UK or military transport - the Ministry of Defence would be the LGD.
- deliberate release from an overseas site - DEFRA would co-ordinate the emergency technical response to an overseas attack, with the FCO (Foreign and Commonwealth Office) leading the overall government response to a terrorist incident that involves or affects UK interests abroad.

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[374] Defence Select Committee, 6th report, session 2001-2002, *Defence and Security in the UK*, July 2002.

[375] Civil Contingencies Secretariat, *Handling a Crisis: Lead Government Departments' areas of responsibility*, www.ukresilience.info/handling.htm

11.8 International arrangements

After the Chernobyl accident in 1986 there has been increasing awareness of the potential for releases of radioactive material from one country to have effects overseas. It served to strengthen both the international arrangements for notification in the event of a release, and the UK's own arrangements for monitoring radiation levels.

Preparation

The OECD Nuclear Energy Agency has co-ordinated a programme of international nuclear emergency exercises since the early 1990s. As with activities at national level, these tabletop exercises have highlighted the need to use modern ways of transmitting data (e.g. the web rather than telephone and fax) and for improvements in communication, both between officials in different countries and with the public and media. At an international level, language poses an additional barrier. According to the Nuclear Energy Agency, English is the official language for international emergency communication, but many emergency management staff are unfamiliar with it and countries would need additional support with translation in an emergency.[376]

Between 1996 and 1999, four exercises were carried out, based on scenarios at power plants in Switzerland, Finland, Hungary and Canada. In 2001, a more extensive exercise took place, simulating an accident at the Gravelines power plant in northern France, involving 54 participating countries and five international organisations. The simulated incident was rated four on the international nuclear event scale (see Annex 6) and would have involved evacuation of 8000 people, based on weather conditions at the time of the exercise. The Gravelines exercise specifically tested arrangements for web-based exchange of information and was followed by discussions on international issues such as third party liability and arrangements for compensation.

Initial response

Notification

In the event of a release from a nuclear facility, IAEA member states are obliged to notify the IAEA, which would then notify other member states. Notification agreements are also in place under the EURATOM treaty.[377] [378] International exercises take place to test all these communication links. In addition, the UK has bilateral notification arrangements with the Danish, Dutch, French, Norwegian and Russian governments. Bilateral arrangements have recently been set up to facilitate direct notification of the Channel Islands authorities in the event of a release from a French or Belgian facility. Arrangements are also in place to notify the Irish authorities in the event of a release from a UK facility.

Radiation monitoring

The UK's radiation monitoring and nuclear emergency response system (RIMNET) was set up in 1988 following the Chernobyl accident, as a means of detecting releases of radioactive material from overseas facilities. It would also provide valuable information in the event of a release within the UK. RIMNET consists of 91 stations across the UK. These collect data hourly which are checked by a central DEFRA computer in London. Any abnormal increase in levels results in

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[376] Nuclear Energy Agency, Organisation for Economic Co-operation and Development, *Experience from International Nuclear Emergency Exercises.* See http://www.nea.fr/html/rp/reports/2001/nea3138-INEX2.pdf

[377] Under article 37 of the EURATOM treaty, member states are obliged to provide the European Commission with advance data onthe potential consequences of *reference* accidents (not *severe* accidents) at nuclear plants which they operate.

[378] Within the EU, the ECURIE (European Community Urgent Radiological Information Exchange) network is a technical system which enables notification of the competent authorities of EU member states and Switzerland in case of a major nuclear accident and then continuously informs them about the current status of the accident and its consequences.

an alert being raised. Additional data could also be provided by approved organisations such as the NRPB, local authorities or nuclear operators. Information on weather patterns would be supplied by the Meteorological Office.

Provision of information

DEFRA has arrangements in place to keep the general public updated via the BBC and the Central Office of Information (COI), and to issue bulletins which would contain advice on local radiation levels, food, milk and water supplies and weather forecasts as well as on specific local issues and advice to farmers. It would also give more detailed information to health authorities, to local authorities and to water boards. Centres in Scotland, Wales and Northern Ireland would co-ordinate the regional response in these areas.[379]

11.9 Releases during transport

The transport of radioactive and nuclear material was discussed in depth in the previous chapter. A response to a release involving material in transport would broadly follow the framework already described in the previous section, as detailed in the document *Dealing with Disaster.*[380] Mutual arrangements for emergency assistance in the event of a release would be provided under the RADSAFE plan.[381]

However, in comparison with plans for fixed installations, emergency plans do not include provisions to protect the general public (e.g. evacuation or sheltering). This is because only a small area is considered likely to be affected in the event of a release and thus the probability of a transport accident having consequences for the public, is considered ‘unforeseeable’. For example, in the case of spent fuel transported by rail, emergency plans specify that all areas within 40 metres of the incident would initially be cordoned off, in the event of a release. Thus, carriers of nuclear and radioactive material are not required to provide members of the public who live on transport routes with information about what to do in the event of an emergency.

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[379] Department for Environment, Food and Rural Affairs, *Response to Radiological Emergencies,* October 1999.

[380] Cabinet Office Civil Contingencies Secretariat, *Dealing with Disaster,* Revised 3rd edition, June 2003.

[381] The RADSAFE consortium is a group of organisations involved in the transport of radioactive material, who have agreed to offer each other mutual assistance (in the form of provision of advice and personnel) in the event of a transport incident involving radioactive material belonging to a member. RADSAFE provides members with services including a 24 hour national notification number, technical support and support in communicating with the emergency services and the media. http://www.radsafe.org.uk/about.htm.

12 Conclusions

Achievement of objectives

The aim of POST's study was to provide Parliamentarians with a comprehensive overview of the risks and consequences of terrorist attacks on nuclear facilities, based on information in the public domain, and to identify options for further analysis. However, as much of the information needed to carry out an exhaustive assessment is classified, the study has been constrained, although the UK nuclear operators and regulators and other official bodies have assisted POST considerably, by providing the POST team with access to sensitive inner areas of Sellafield and to classified background briefings. Moreover, POST was requested to omit some information from this report, to avoid highlighting sensitive knowledge that might be of use to terrorists, even though some of it was already in the public domain. Also, although this document has been extensively reviewed, some organisations felt that the review process was incomplete because reviewers had to base their comments on publicly available information.

Some of the key issues raised in the course of the study are as follows:

- There is sufficient information to identify possible ways that terrorists might bring about a release of radioactive material from the facilities examined in this report, but this is not sufficient to draw definite conclusions on the likelihood of a successful attack, or on the size and effects of any release.
- Concern has focussed mainly on facilities that house large inventories of radioactive material in a dispersible form. However these generally have high levels of protection compared with other facilities with smaller inventories. An attack on a 'softer' target could still cause widespread panic and disruption.
- Detailed emergency plans are in place for areas within a few kilometres of nuclear sites and could be extended to tens of kilometres if necessary. Some analysts believe that the UK should strengthen arrangements for dealing with releases which could potentially affect wider areas.[382] Several government initiatives are underway to improve UK resilience to CBRN terrorism – such as the 'New Dimension' programme within ODPM.[383]
- Reports in the public domain also discuss the risk of terrorist attacks in the context of nuclear facilities yet to be built, such as radioactive waste storage facilities. These have not been discussed in depth in this report. Many analysts believe that policy decisions on the future management of radioactive waste need to take into account the vulnerability of surface stores to terrorist attack.[384] [385]

The need for transparency versus the need to protect sensitive information

The nuclear authorities face an inevitable conflict between the need to protect sensitive information, and the need to keep the public informed. The events of September 11th 2001, severely constrained earlier efforts of many organisations, for example the Nuclear Installations Inspectorate, to be more open about their activities. Some measures continue to be taken to inform the public – for example OCNS has published an annual report on the State of Security in the Civil Nuclear Industry since 2002. However, if sufficient information were made available for

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[382] Large and Associates, *Local Authority Emergency Planning in the locality of UK nuclear power plants,* 2002.

[383] The 'New Dimension' programme within the Office of the Deputy Prime Minister aims to improve the ability of the fire and rescue services to respond to CBRN emergencies.

[384] House of Lords Science and Technology Committee, First Report, Session 2001-2002, *Managing Radioactive Waste: the government's consultation,* November 2001.

[385] The Royal Society, *Developing UK Policy for the Management of Radioactive Waste,* 2002. http://www.royalsoc.ac.uk/files/statfiles/document-173.pdf

a member of the public to make an informed decision about the level of the threat faced from potential terrorist attacks at nuclear facilities, there is a fear that the same information could aid a terrorist planning an attack. Thus a very high level of confidence must be placed in the safety and security regulators.

Scope for further work

There are few detailed assessments of the physical robustness of nuclear facilities to terrorist attack. Those carried out by the nuclear operators are usually classified and although they are subject to regulatory scrutiny, they are not subject to a public peer review process due to their sensitivity. If a detailed assessment were to be carried out based on publicly available information, a range of assumptions would have to be made about the design of the facility. Moreover, it would not be easy to put the results in context without some understanding of terrorist intentions and capabilities. Also, it is not the UK government's policy to comment on security issues, so there would be no response to such a study.

Many analysts have pointed out that the sabotage of a range of other targets such as petrochemical plants or gas storage facilities could also result in the dispersal of hazardous material. An analysis of the vulnerability of nuclear facilities relative to other facilities would be a useful exercise.

13 Annexes

Annex 1: Radioactive, nuclear and fissile materials

Radioactive materials

Radioactive materials have unstable atomic nuclei and decay by emitting 'ionising radiation' (see box below). There are two key properties used to describe radioactive materials.

- **activity (or radioactivity)** - this is the rate of radioactive decay, and is a measure of how much ionising radiation is emitted. The international unit for the rate of decay is the Becquerel (Bq).
- **half-life** - the time required for half the atoms in a particular radionuclide sample to decay. It is therefore a measure of how the activity of a given sample reduces with time. Thus after 10 half lives the activity of a sample will be under 0.1% of the original value. Half lives can vary from a few millionths of a second, to hundreds of thousands of years. It can thus be seen that the longer the half-life of a given radioactive element the lower will be its activity.

Another important property is the energy emitted as part of the decay process (see Box 13-1). The greater the energy, the more harm will be done to living tissue. The energy depends on the nucleus itself, and is not related to activity or half-life. The usual unit is the electron volt (eV) and values can range from a few eV to up to 5.3 MeV (million eV). To illustrate, a medical X-ray machine will produce radiation of about 0.15 MeV.

Box 13-1 Radioactivity and ionising radiation

Ionising radiation has the ability to strip the electrons away from atoms and can therefore damage living tissue as it passes through it. Most materials have radioactive isotopes, some of which occur naturally. Others can be manufactured. The different types of ionising radiation are:

- **alpha particles** - atomic nuclei consisting of 2 protons and 2 neutrons. They are intensely ionising but are only weakly penetrating – they can be stopped by a thin sheet of paper or human skin.
- **beta particles** - electrons (though they can also be positrons – positively charged electrons). They are more weakly ionising than alpha particles but more penetrating. They can be stopped by e.g. a sheet of wood or plastic and are not as penetrating as gamma radiation. However, when stopped they emit a secondary radiation similar to X-rays.
- **gamma rays** - are high energy radiation similar to X-rays. They are very penetrating and can only be stopped by thick shields of heavy materials e.g. concrete walls, lead shielding or water.
- **neutrons** - these are even more penetrating than gamma rays as well as being strongly ionising. They are mainly emitted by nuclear fission (see below) rather than by radioactive decay.

Fissile and nuclear materials

Nuclear fission occurs when heavy atomic nuclei fragment into smaller pieces, releasing energy and neutrons in the process (see Figure 13-1). The nuclei of some materials can fission spontaneously, while others will only do so when they absorb a neutron. In ‘fissile materials’ the neutrons produced by fission can go on to initiate further fissions in the same material,[386] under certain conditions. The reaction then becomes a self-sustaining ‘chain reaction’. This is the principle behind nuclear bombs and nuclear reactors. In a nuclear bomb, the number of successive fission reactions (which are only a fraction of a second apart) can multiply very rapidly, resulting in an explosive release of energy. In a nuclear reactor, the chain reaction takes place in a more controlled manner, with the number of fission reactions taking place at any given time being roughly constant. This makes it possible to harness the energy released.

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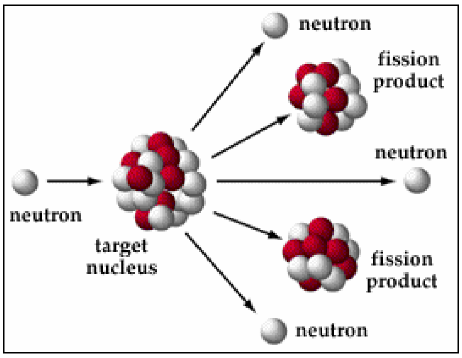
[386] For this to occur, the neutron must be travelling at the correct speed. In some instances a ‘moderator’ is required to slow the neutrons down.

Figure 13-1 Nuclear fission



The most important fissile materials are certain isotopes of uranium and plutonium. These are uranium-235 or U^{235} (a type of uranium with a total of 235 protons and neutrons in its nucleus) and plutonium-239 (Pu^{239}).

Box 13-2 Uranium and plutonium

Natural uranium contains over 99% uranium-238 (U-238), which cannot sustain a nuclear chain reaction. Uranium-235 (U-235) is the only isotope of uranium which can sustain a nuclear chain reaction, and it is found in natural uranium in concentrations of less than 1%. For most applications, uranium must be 'enriched' to increase the proportion of U-235. Most nuclear power plants use either natural uranium or **low enriched uranium** (LEU) containing 2.5-3.5 % (U-235), while **highly enriched uranium** (HEU), defined as uranium containing over 20% U-235, is used in naval propulsion units and in many research reactors . Uranium used in the fabrication of nuclear weapons is generally enriched to over 90% and is known as 'weapons-grade' uranium, but in principle any HEU could be used to make crude nuclear weapons. There are therefore greater security concerns surrounding the use of HEU than the use of LEU or natural uranium. Uranium does not present a significant radiological hazard in any form, as neither U-238 or U-235 are highly radioactive- although as it is a heavy metal, it is chemically toxic.[387]

Plutonium has been found to occur naturally in minute quantities, but this is so rare that it is considered to be a man-made substance. Pu-239, the only isotope of plutonium that can sustain a nuclear chain reaction, is produced in nuclear reactors when U^{238} absorbs a neutron. Some military reactors were developed solely to produce Pu-239 for use in nuclear weapons. In any nuclear reactor, a certain fraction of the energy generated comes from the fission of Pu-239 – the exact amount depends on the reactor and the fuel type. Many higher isotopes of plutonium are also generated in nuclear reactors (e.g. Pu-240, Pu-241) but they have no military application. In a way similar to uranium, there is 'weapons-grade' and 'reactor-grade' plutonium. Weapons-grade plutonium contains over 92% Pu-239 while reactor-grade contains 60% or less. There are security concerns surrounding the use of both reactor grade plutonium and weapons grade plutonium (see Chapter 10).

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[387] Although HEU containing over 80% U-235 is radioactive enough to require handling with glove boxes, due to the fact that it contains U-234, which is more radioactive than the other two isotopes.

Annex 2: Nuclear facilities in the UK[388]

Licensed fuel cycle sites

- Capenhurst near Chester - divided into two sites - a uranium enrichment plant operated by URENCO and an earlier gaseous diffusion plant (now closed) managed by BNFL.
- Dounreay, northern Scotland - a former UKAEA research site which first opened in 1955 as the centre for UK fast reactor research. Half of UKAEA's liabilities are located here.
- Drigg - a BNFL-operated shallow disposal site in Cumbria for low level radioactive waste and some intermediate level radioactive waste contaminated with plutonium (the ILW is due to be removed by 2006).
- Harwell, Oxfordshire - headquarters of the UKAEA and a former research site (for both civilian and military applications). The site has a Category II store containing spent nuclear fuel and plutonium-contaminated material.
- Sellafield, Cumbria - the UK's largest civil nuclear site, operated by BNFL. Activities include reprocessing, storage of spent fuel, MOX production, and processing of radioactive waste.
- Springfields near Preston in Lancashire - a BNFL site which manufactures fuel for Magnox and AGR reactors.
- Windscale, Cumbria - a separate licensed site at Sellafield in Cumbria run by the UKAEA. Activities are focussed on decommissioning and waste management.
- Winfrith, Dorset - a former UKAEA research site. All facilities have ceased operation and are now being decommissioned.

Table 1 Operational and decommissioning power plants

Operational power plant (no. reactors ; type)	**Operator**	**Commissioned**	**Scheduled shutdown date (where available)** [389]	**Scheduled defuelling date (where available)**
Chapelcross (4 Magnox)	BNFL	1959	2005	2007
Dungeness A (2 Magnox)	BNFL	1965	2006	2009
Sizewell A (2 Magnox)	BNFL	1966	2006	2009
Oldbury (2 Magnox)	BNFL	1968	2008	2010
Wylfa (2 Magnox)	BNFL	1971	2010[390]	2012
Hunterston B (2 AGR)	British Energy	1976	2011	
Hinkley Point B (2 AGR)	British Energy	1976	2011	
Heysham 1 (2 AGR)	British Energy	1983	2014	
Hartlepool (2 AGR)	British Energy	1983	2014	
Dungeness B (2 AGR)	British Energy	1983	2008	
Heysham 2 (2 AGR)	British Energy	1988	2023	
Torness (2 AGR)	British Energy	1988	2023	
Sizewell B (1 PWR)	British Energy	1995	2035	
Decommissioning plants			Shutdown date	
Bradwell (Magnox)	BNFL		2002	**2005**
Calder Hall (4 Magnox)	BNFL	1965	2003	**2007**
Hinkley Point A (Magnox)	BNFL	1965	2001	**2005**

Licensed military sites

- Atomic Weapons Establishment (AWE) at Aldermaston and Burghfield in Berkshire: undertake the design, manufacture and servicing of Trident nuclear warheads as well as research and development and decommissioning activities.
- Devonshire Dock Complex, Barrow-in-Furness, Cumbria - installation of reactor cores into new

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[388] Main sources: Office for Civil Nuclear Security, *The State of Security in the Civil Nuclear Industry,* 2003; Health and Safety Executive, *Names and addresses of firms holding nuclear site licenses,* http://www.hse.gov.uk/nsd/licensees/pubregister.pdf

[389] HC Deb, 15th Jun 2004, 821W.

[390] Subject to Periodic Safety Review in 2005.

nuclear submarines; operated by BAE Systems Marine Ltd.
- Devonport Royal Dockyard, Devon - refitting, refuelling and maintenance of nuclear submarines, operated by DML Devonport.
- Rosyth Dockyard, Scotland - decommissioning of nuclear submarines, operated by Babcock Engineering Services.
- Neptune Reactor, Raynesway, Derby - low power test reactor operated by Rolls Royce.
- Nuclear Fuel Production Plant Raynesway, Derby - operated by Rolls Royce.

Other military sites involved in nuclear activities and mentioned in this report include:
- Vulcan Naval Test Reactor Establishment, northern Scotland - development work and training; operation of land-based prototype submarine propulsion reactor.
- Faslane, Scotland - nuclear submarine base.

Other licensed sites
- Silwood Park, Ascot, Berkshire - Research reactor operated by Imperial College of Science and Technology,University of London.
- Amersham plc (now part of GE Healthcare), with four nuclear licensed sites at Amersham, Cardiff and Harwell: the main users of radioisotopes in the UK.
- Berkeleynorth of Bristol - site of a decommissioned Magnox power station. The site holds some LLW, ILW and irradiated fuel.
- Hunterston A, Scotland - a defuelled Magnox plant which ceased operating in 1990. Disposal of plant and equipment is under way. No fuel elements remain on-site but some ILW remains.
- Trawsfynedd, North Wales - a defuelled Magnox plant, which ceased operating in 1993. This was the only UK power station not built on the coast. Some ILW and LLW remain on-site.
- Billingham, Cleveland - site of ICI's decommissioned TRIGA reactor operated by ICI. The fuel has been removed to Dounreay.
- Birniehill Scottish Universities Research and Reactor Centre, located within the Scottish Enterprise Technology Park in East Kilbride - the decommissioned research reactor & associated facilities have been removed from the site but some active laboratories remain.

Figure 13-2 Map showing location of nuclear sites in the UK

Image reproduced by kind permission of Nirex.

Annex 3: Nuclear facilities in France

France has 59 operational reactors (including a fast breeder research reactor) and obtains over 75% of its electricity from nuclear power. There is also a reprocessing facility located at Cap de la Hague and operated by COGEMA (see Figure 13-3)

Nuclear power plants

There are six sites (a total of 20 operational reactors and one decommissioned reactor) close to the northern coast of France, three of which are actually located on the shores of the English Channel. All French nuclear plants are operated by Electricité de France (EDF).[391]

- Flamanville: located on the Channel coast in Normandy. It has two reactors and is built on a platform located at 12.4 metres above sea level.
- Penly: located on the Channel coast in Seine-Maritime. It has two reactors, commissioned in 1990 and 1992. The plant and the offices are at sea level.
- Gravelines: located on the Channel coast half-way between Dunkirk and Calais. It has six reactors, which produce almost 10% of France's nuclear power.
- Chooz: located close to the Belgian border. The Chooz B plant has two reactors that started operating in 1999, while the Chooz A plant has one reactor that is currently being decommissioned.
- Cattenom: located on the banks of the Moselle river in the Lorraine region of France. It has four reactors.
- Paluel: located in Normandy close to St Valéry-en-Caux on the Channel coast between Dieppe and Fécamp. The site has four reactors that have been operational since 1984.

Reprocessing plants

- Cap de la Hague (operated by COGEMA) in Northern France: this plant commenced operations in 1966 and reprocesses spent fuel from France’s light water reactors as well as from several other European countries and Japan.
- Marcoule (operated by COGEMA) in Southern France: this plant commenced operations in the 1950s and reprocessed fuel from France’s gas-cooled reactors. The last fuel was reprocessed in 1997 and activities are now focussed on decommissioning.

Radioactive waste disposal sites

- Centre de la Manche disposal facility: this is a former radioactive waste disposal facility located about 20 km west of Cherbourg close to Cap de la Hague. It was used between 1969 to 1994 as a surface disposal site for certain types of short-lived radioactive waste.
- Centre de l’Aube disposal facility: this facility is the successor of the Centre de la Manche facility, and is France’s current site for low level radioactive waste disposal. The facility started accepting radioactive waste in 1992.

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[391] EDF is a group of different companies involved in generation and distribution of electricity in France and overseas.

Figure 13-3 Nuclear facilities in France and Belgium

Source: International Nuclear Safety Center at Argonne National Laboratory, October 2002.
(Large circles indicate nuclear power plants)

Annex 4: Nuclear facilities in Belgium

Power plants

Belgium has 7 PWR units at two sites, which started operating between 1975 and 1985 and which are operated by the nuclear operator Electrabel.

- Tihange: 3 PWR units.
- Doel: 4 PWR units.

Other sites

- Mol-Dessel: fabrication of MOX fuel for LWRs as well as site of earlier reprocessing activities and processing of radioactive waste.
- BR-3: a research PWR commissioned in 1962, currently being decommissioned.

Annex 5: International agreements on safety and radiation protection

International agreements affecting the operation of nuclear facilities broadly fall into three categories: those which directly aim to protect workers and the public from radiation (e.g. by imposing limits on radiation exposure); those which aim to combat nuclear proliferation (e.g. by safeguarding nuclear material) and those which set standards for the physical protection of nuclear material.

International agreements on safety and radiation protection

The earliest institutional arrangements to protect people against the biological effects of radiation were triggered by the development of X-ray machines for medical diagnosis at the end of the 19th century. Such considerations led to the establishment of the International Commission on Radiological Protection (ICRP) in 1928. At this time, the main focus was on protecting workers against exposure to radiation. However, after the second world war, and in the aftermath of the Hiroshima and Nagasaki nuclear attacks, attention began to focus on protecting the general public from the effects of excessive radiation exposure.

As nuclear power and weapons testing (particularly atmospheric bomb tests) expanded during the 1950s, concerns accelerated and the ICRP identified maximum levels of exposure for both workers and the public. In 1957, the UN established the International Atomic Energy Agency (IAEA) to help to ensure that the nuclear industry worldwide could apply the ICRP's recommendations (see Box 13-3).

Box 13-3 Principles of radiological protection

Protection against potentially adverse effects of radiation is founded on a conceptual framework proposed by the International Commission on Radiological Protection (ICRP 60, 1990). This involves three principles:
justification – no practice involving exposure to radiation should be adopted unless it provides sufficient benefit to the exposed individuals or society to offset any detriment it causes. Such detriment may include other social and economic considerations alongside any caused by radiation.
optimisation – it is necessary to consider how best to use resources in reducing the radiation risk to individuals and the population. The broad aim should be that the magnitude of individual doses, the number of people exposed, and the likelihood of incurring potential exposure should all be kept as low as reasonably achievable, economic and social factors being taken into account. In the UK this is interpreted 'as low as reasonably practicable' (the ALARP principle – discussed in the next section).
limitation – exposure should be subject to dose limits, or to some control of risk. These are aimed at ensuring that no individual is exposed to radiation risks deemed to be unacceptable.

In the event of an accident, radiation protection principles should be applied retrospectively. Here, justification should seek to ensure that the intervention does more good than harm. Optimisation should ensure that the form, scale and duration of the intervention are such that it delivers maximum benefit relative to its cost.

Based on the ICRP principles of radiological protection, the UN International Atomic Energy Agency established a set of safety standards for nuclear facilities. These specify the basic requirements that must be satisfied to ensure safety, but do not themselves contain explanations of how to meet the requirements. The IAEA operates a Commission on Safety Standards. The CSS comprises committees dealing with safety standards for nuclear power stations, radiation protection, waste and transport.

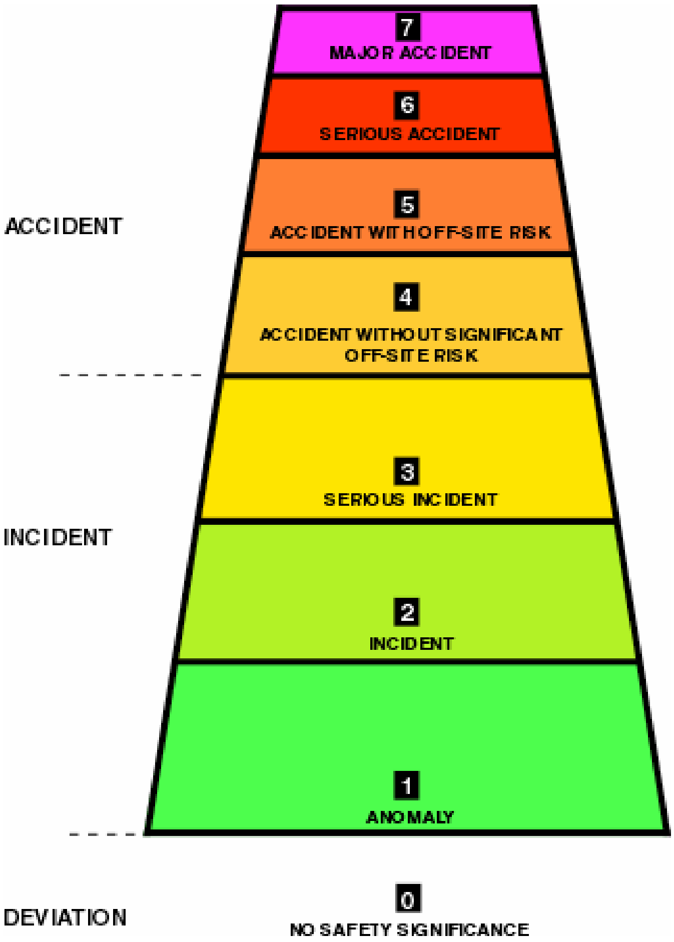
In parallel with international developments, legislation was developed in Europe on safety standards for radiation protection. The Basic Safety Standards directive under the 1957 EURATOM treaty was revised by the European Union in 1996 to incorporate the ICRP's principles of radiological protection.

Other international agreements relating to safety and radiation protection include the Convention on Nuclear Safety, the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management. Under these conventions, contracting parties must take steps to ensure safe and environmentally sound operation and management of nuclear facilities, radioactive waste and spent fuel, and to submit national reports on the measures they have taken to implement their obligations. Key international agreements relating to arrangements in the event of accidents include the Paris and Brussels Conventions on Third Party Liability in the event of a nuclear accident and the Convention on Mutual Assistance in the event of a nuclear accident.

Annex 6: the International Nuclear Event Scale

The International Nuclear Event Scale (INES) is a concept introduced by the IAEA following the Chernobyl accident in 1985. It provides a common standard against which the significance of events at nuclear facilities can be assessed (in terms of radiological release and the level of damage to the facility), to improve the reporting of nuclear events and to put them in perspective. The scale ranges from 0 for an event with no safety significance to 7 for a major accident such as Chernobyl. Only events at level 4 and above are associated with off-site release of radiation.

Figure 13-4 The International Nuclear Event Scale



Annex 7: Statement from BNFL

BNFL issued the following statement to POST on 25th June 2004, regarding the public domain reports which predict very serious consequences for the public if the High Level Waste Tanks at Sellafield were to be targeted by hijacked aircraft, cited in this report.

'We are concerned that POST has referred to public-domain reports that predict very serious consequences for the public if the High Level Liquid Waste Tanks at Sellafield were to be targeted by a highjacked aircraft. None of the authors of these reports have access to the current engineering and construction information that is necessary to undertake a credible study of the likely consequences. For that reason BNFL considers that their conclusions are unsubstantiated, entirely speculative and significantly exaggerate the consequences.

We wish to make clear that professional engineering assessments, using the actual engineering and constructional information (that for obvious reasons must remain confidential) have concluded the following:

BNFL accepts that whilst commercial aircraft impact was not included as a design basis event for this building, the provision of a massive reinforced bulk concrete structure of adequate thickness to shield the Highly Active Liquor (HAL) inventory also results in massive structural strength.

Since 9/11, BNFL has undertaken impact studies which are confidential and not suitable for placement in the public domain, but which have been made available to the Nuclear Installations Inspectorate (NII) and the Office for Civil Nuclear Security (OCNS). The studies provide high confidence that the secondary containment and hence primary containment (which is located within the massive reinforced bulk concrete structure) will survive credible aircraft impact scenarios. Given the amount of energy associated with a commercial aircraft this also provides confidence that other high energy incidents could be tolerated by the building without significant damage to the bioshield (secondary containment). This is a fundamental change from the currently implemented external hazards assessment covering aircraft impact, which assumes a loss of containment.

Thus we do not believe that the physical effects of an aircraft impact upon this building would result in a loss of bulk shielding or containment. This is because secondary and primary containment barriers will prevent significant direct consequences being realised as a result of an external hazard. This is a significant step forward in our understanding.

BNFL has also undertaken studies to consider the effects of potential aviation fuel fires following aircraft impact. Based upon the studies the risks are considered to be low, because the bulk concrete structure will survive and concrete has a much better tolerance of fire and heat than has structural steelwork. An aviation fuel fire would either burn out quickly or would be extinguished well before the HAL temperature had risen to a level that would result in a significant consequence. However if all other recovery measures failed, the HAL can be cooled via controlled flooding of the containment cells.

BNFL has procured two airport-standard foam tenders, to supplement existing fire fighting capability, that will ensure that an appropriate operational response can be achieved if an aviation fuel fire were to occur anywhere on the Sellafield site.'

Annex 8: the responsibilities of the devolved administrations

Wales
In the event of an emergency in Wales, a Welsh Emergency Co-ordinator would take the lead in co-ordinating the response. The Emergency Co-ordination Centre at the Welsh Assembly Government would help to facilitate the flow of information between Wales and Whitehall and vice versa. Consequence management for devolved functions following terrorism within Wales would fall to the Welsh Assembly Government and its own lead department arrangements.

Scotland
In the event of any emergency that affected Scotland, the Scottish Executive (SE) is responsible for the implementation of emergency plans. The Consents and Emergency Planning Unit within the Energy Division (ETLLD)[392] of the SE would take the lead in the event of a release from a civil nuclear site in Scotland. The SE would set up a Scottish Executive Emergency Room in Edinburgh, from which briefing of ministers and departments, and co-ordination of departmental action, would take place. Arrangements are in place for Ministers to activate the Scottish Emergency Co-ordinating Committee to assist in the co-ordination of an emergency response if necessary.

Northern Ireland
Under a Devolved Administration the Office of the First Minister and Deputy First Minister (OFMDFM) has overall responsibility for the implementation of the UK's emergency plans in Northern Ireland, with the Central Emergency Planning Unit within this office co-ordinating the plans of different government departments and agencies. Under Direct Rule, this is the responsibility of the Secretary of State for Northern Ireland. The Department of the Environment for Northern Ireland is the lead department for responding to radiological releases. The Northern Ireland Technical Advisory Group, made up of representatives from across government, would advise on the implementation of emergency plans in Northern Ireland and on the need to introduce countermeasures.

Annex 9: Print media coverage of nuclear security issues

It is beyond the scope of this report to conduct a full analysis of how issues relating to nuclear security are reported in the media. However, a preliminary examination of the coverage of two issues in national print media[393] has been carried out for the purposes of this report using the 'Lexis Nexis' search engine:

- References to Sellafield in print media before and after September 11th 2001
- Print media coverage of MOX fuel shipments between the UK and Japan in 1999 and 2002.

References to Sellafield
A simple keyword search for articles in the national press containing the words 'Sellafield' and 'terrorism' provides a preliminary indication of how Sellafield has been linked with the potential for terrorist attacks. Media coverage greatly increased after September 11th 2001, with over 200 articles appearing between September 2002 and January 2003. Although levels of coverage declined after this initial period they have remained higher than before September 11th 2001. A number of smaller peaks can also be seen in Figure 13-5 which cover specific events, not all of which are security related, as listed in the table below.

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[392] Enterprise, Transport and Lifelong Learning Department.

[393] National print media means all UK newspapers (including local papers) and journals.

Figure 13-5 Articles containing keywords 'Sellafield' and 'terrorism' in print media.

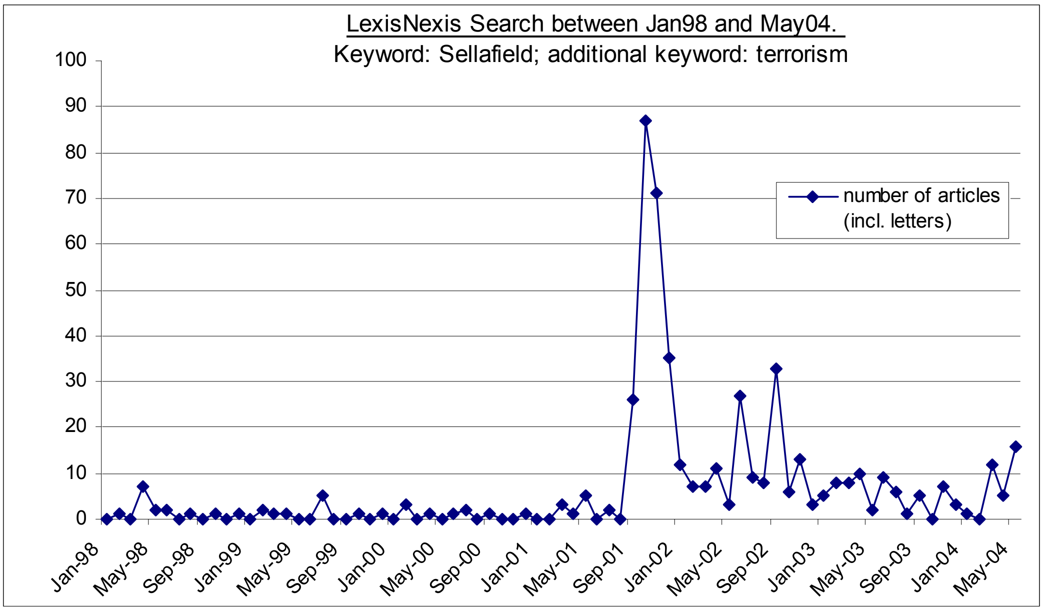

Table 2 Events linked to media coverage of Sellafield

Peak	Subject of coverage
April 1998	Resignation of UKAEA Chief Constable; security exercises at Sellafield and Dounreay.
July 1999	First MOX shipment from UK to Japan.
February 2000	Coverage of MOX data falsification story; debate over future of reprocessing at Sellafield.
May 2001	New Scientist article on the implications of theft of MOX by terrorists
September 2001	Concerns over potential for terrorist attacks at Sellafield after events of September 11th in USA.
April 2002	Coverage of European Parliament Petition Committee meeting on discharges from Sellafield and Cap de la Hague after publication of WISE report.
June 2002	Coverage of planned MOX shipment from Japan to UK.
September 2002	MOX shipment approaches Britain, coverage of Greenpeace protests over shipment.
April 2003	Protest campaign over discharges from Sellafield.
May 2004	Parliamentary questions on alleged breaches of no-fly zones around nuclear plants.

MOX shipments in 1999 and 2002

A comparison of coverage of the two shipments reveals an increased focus on terror attacks by sub-state terrorist groups and potentially less focus on nuclear non-proliferation efforts in the 2002 coverage. A keyword such as 'MOX' revealed 16 articles between 30/06/1999 and 31/07/99 and 41 between 01/09/2002 and 01/10/2002. For the first shipment (Figure 13-6), coverage focussed largely on Greenpeace's planned protests. Five articles mention terrorism and three articles contain quotes from environmental groups implying that the MOX shipments undermine nuclear non-proliferation efforts. With the second shipment almost half of the articles (20) mention terrorism, raising concerns over security in the light of the events of September 11th 2001.[394] However, none mentions nuclear non-proliferation.

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[394] For example *'Are we safe from pirates of terror?'* Daily Mail, 17th September 2002.

Figure 13-6 MOX shipment from the UK to Japan (19th July 1999)

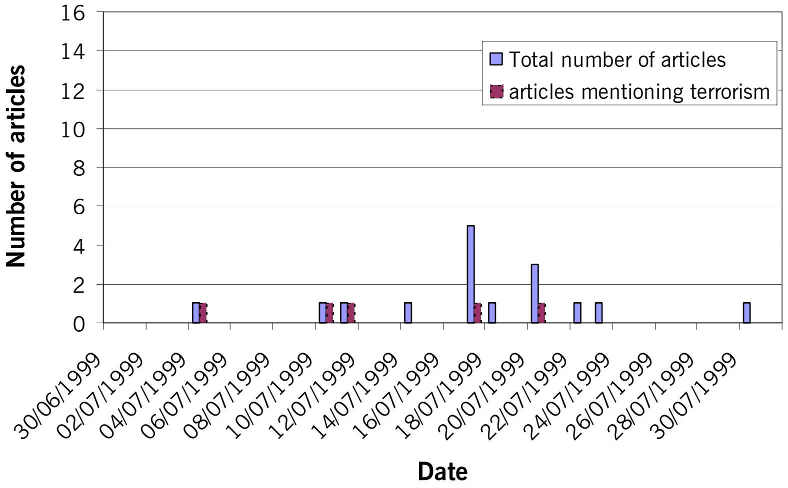
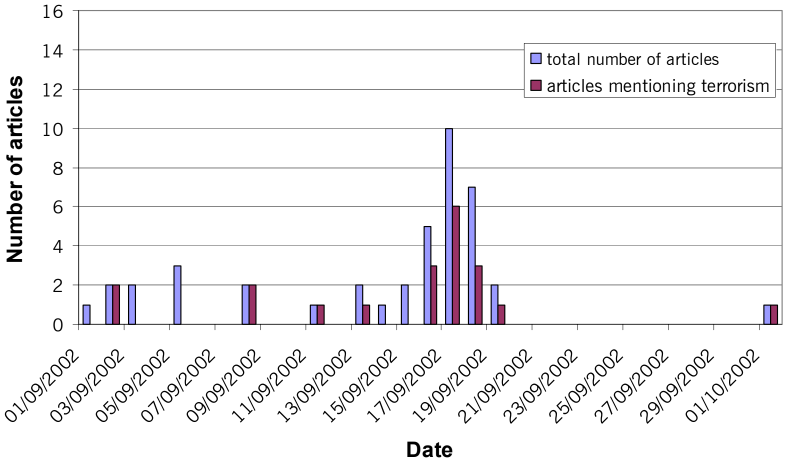


Figure 13-7 Return MOX shipment from Japan to the UK (17th September 2002)



14 Glossary and Abbreviations

Abbreviation/definition	**explanation**
Actinide	Heavy elements formed by uranium and plutonium absorbing neutrons. The main long lived ones are neptunium, americium and curium.
Aerosol	A suspension of solid or liquid particles in the air; typical dimensions range from less than 1 micron to over 100 microns.
AGR	Advanced Gas Cooled Reactor
ANSTO	Australian Nuclear Science and Technology Organisation
BE	British Energy
Biological half-life	The time required for half the quantity of a drug or other substance deposited in a living organism to be metabolised or eliminated by normal biological processes.
BNFL	British Nuclear Fuels Plc
BWR	Boiling Water Reactor
CBRN	Chemical, Biological, Radiological and Nuclear
CEGB	Central Electricity Generating Board
COGEMA	A company that provides services to the civil nuclear industry
CORE	Cumbrians Opposed to a Radioactive Environment
DBT	Design Basis Threat
DEFRA	Department of Food, Environment and Rural Affairs
DTI	Department of Trade and Industry
EA	Environment Agency
EDF	Electricité de France is involved in electricity generation and distribution both in France and overseas.
ERL	Emergency Reference Levels
Fissile material	Material whose nucleus can undergo nuclear fission when it absorbs a low energy (ideally zero energy) neutron. Fissile materials can sustain nuclear chain reactions.
GAO	US General Accounting Office
HAL	Highly Active Liquor
Half-life	the time required for half the atoms in a particular radionuclide sample to decay.
HAST	Highly Active Storage Tanks
HEU	Highly Enriched Uranium
HLLW	High Level Liquid Waste
HMIC	Her Majesty's Inspectorate of Constabulary
HPA	Health Protection Agency
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency: the main international body with expertise in the field of nuclear safety and security. It was set up in 1957 as an independent body within the United Nations to promote peaceful uses of nuclear technology.
ICRP	International Commission on Radiological Protection
IRSS	Institute for Resource and Security Studies
Isotopes	Forms of the same element with the same number of protons but different numbers of neutrons in their nucleus, and therefore different masses.
LEU	Low Enriched Uranium
LGA	Local Government Association
LWR	Light Water Reactor
MDP	Ministry of Defence Police
Micron	1 micron=1 millionth of a metre
MoD	Ministry of Defence
MOX	Mixed Oxide Fuel
mSv	millisieverts
NGO	Non Governmental Organisation
NII	Nuclear Installations Inspectorate
Nirex	Nuclear Industry Radioactive Waste Executive, formed to provide and manage facilities for the safe disposal of radioactive waste in the UK

NRC	US Nuclear Regulatory Commission
NRPB	National Radiological Protection Board
Nuclear Energy Institute (NEI)	Nuclear Energy Institute: policy organisation of the nuclear energy and technologies industry in the USA.
Nuclear facility	Defined by the International Atomic Energy Agency as *'a facility and its associated land, buildings and equipment in which radioactive materials are produced, processed, used, handled, stored or disposed of on such a scale that consideration of safety is required'*. However for the purposes of this report the term 'nuclear facility' is also used to refer to shipments of radioactive material.
Nuclear fission	The break up of a heavy atomic nucleus into two or more lighter nuclei, generally accompanied by release of neutrons and energy.
Nuclear installations	Defined by the IAEA as *'A nuclear fuel fabrication plant, nuclear reactor (including subcritical and critical assemblies), research reactor, nuclear power plant,spent fuel storage facility, enrichment plant or reprocessing facility' … 'essentially any authorized facility that is part of the nuclear fuel cycle except radioactive waste management facilities'.*
Nuclear material	a term used to describe both fissile materials and non fissile materials suitable for transformation into fissile materials.
NuSac	Nuclear Safety Advisory Committee within the HSE
OCNS	Office for Civil Nuclear Security
ODPM	Office of the Deputy Prime Minister
PWR	Pressurised Water Reactor
Radioactive material (radionuclide)	Material whose atomic nuclei are unstable and which decay by spontaneously emitting ionising radiation.
Radioisotope	A radioactive isotope of a chemical element
RWMAC	Radioactive Waste Management Advisory Committee
SAP	Safety Assessment Principles
SEPA	Scottish Environment Protection Agency: environmental regulator in Scotland
THORP	Thermal Oxide Reprocessing Plant, Sellafield
UKAEA	United Kingdom Atomic Energy Authority
UKAEAC	United Kingdom Atomic Energy Authority Constabulary
UNDP	United Nations Development Programme
UNICEF	United Nations International Children's Fund
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
Volatile	capable of readily changing from solid or liquid to vapour.

Acknowledgements

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External consultants

The Parliamentary Office of Science and Technology wishes to thank Dr Jeffrey Lewins (University of Cambridge) and Robert Skelton (University of Cambridge), for advice on technical issues during preparation and review of this report.

Acknowledgements

The Parliamentary Office of Science and Technology wishes to thank the organisations and individuals listed below who assisted with preparation or reviewed the draft report. This report has been produced by POST and these organisations and individuals do not necessarily endorse its contents.

Nuclear Installations Inspectorate
Department of Trade and Industry
Office for Civil Nuclear Security
British Nuclear Fuels Plc
Jean McSorley, Pete Roche (Greenpeace UK)
British Energy
US Nuclear Energy Institute
UKAEA
Department for Transport
National Radiological Protection Board
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House of Commons Defence Select Committee
TAB, Germany
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