sustainable development commission

The role of nuclear power in a low carbon economy

Paper 5: Waste and decommissioning

An evidence-based report by the Sustainable Development Commission with contributions from Nirex and AMEC NNC

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1 EXECUTIVE SUMMARY AND INTRODUCTION

This report is concerned with the radioactive waste management and decommissioning implications of the construction of new reactors in the UK.

Radioactive waste and spent nuclear fuel is currently stored in the short and medium term (of the order decades) in interim storage facilities. These stores are regulated by the Health and Safety Executive (HSE), and the Environment Agency (EA -England and Wales) or Scottish Environmental Protection Agency (SEPA)-Scotland). Most low-level waste (LLW) is currently disposed of in the national low level waste disposal facility at Drigg, in Cumbria which has been in operation since 1959. Some LLW is stored, as it does not meet the facility acceptance criteria. However, the UK currently has no long-term policy for the management of intermediate and high level and intermediate level radioactive wastes (HLW, ILW) and this is the subject of the ongoing Managing Radioactive Waste Safely (MRWS) programme being run under the aegis of Defra and the Devolved Administrations.

Any decision to build new nuclear power stations will be controversial. The inability to demonstrate and implement an adequate long-term waste management policy has been seen by many as the "Achilles heel" of the nuclear industry. The debate on new nuclear build has often been centred around issues of waste management; this is expected to continue. For example, is it right to produce the additional wastes, which a new build programme would create, when no current long-term management solution exists for the wastes already in existence? The costs and timing of decommissioning nuclear power stations have also been the subjects of arguments for and against new build. However, irrespective of a new build programme, the current waste legacy exists and has to be dealt with.

Section 2 of the report provides a summary of the development of radioactive waste management policy and its implementation over the years. In particular it traces, the history in terms of Government policy announcements on long-term management against the efforts to attempt to site disposal facilities, culminating in the 1997 failure of the deep repository siting programme.

This led to a number of initiatives post-1997 to address the issue which eventually led to Defra and the Devolved Administrations' Managing Radioactive Waste Safely programme, designed to allow the UK to address its long-term radioactive waste management legacy. The current phase of this process is being overseen by the Committee on Radioactive Waste Management (CoRWM) who are to make recommendations on long-term management options in July 2006.

Lessons learned from past siting failures play a part in future progress, and Section 2 indicates the legal and social contextual changes that have taken place which may allow decisions on progress to be seen as legitimate. Defra and the Devolved Administrations are also currently undertaking a consultation programme looking at the Future Policy for the Management of Low Level Radioactive Waste in the UK, which has been established in recognition of the fact that the future LLW arising is expected to exceed the existing capacity of the Drigg disposal facility. The Government's current decommissioning policy is also summarised in this section and this exemplifies increased stakeholder involvement in industry decisions.

Section 3 considers in more detail current waste management practice, covering aspects of the radioactive waste inventory as well as the impact of declaring as waste some radioactive materials not yet classified as waste, and other scenarios. Despite a lack of Government policy on the long-term management of wastes, they still have to be dealt with, and Section 3 describes the arrangements for packaging wastes. Decommissioning is also discussed here, including cost aspects. The role of spent fuel reprocessing is also described. Decommissioning and waste management costs and funding are also discussed.

Summaries of overseas' decommissioning and radioactive waste management programmes are provided in section 4. This covers both near-surface and deep repository projects, examples of decommissioning and a summary of financing arrangements. The section contains two case studies: one for the decommissioning of the Spanish Vandellós I reactor and one for the whole Finnish programme.

Section 5 considers new build in the UK and the implications for various aspects of waste management and decommissioning including the MRWS programme, inventory and operational waste management implications, burning plutonium in new reactors, decommissioning, and costs and financing.

2 RADIOACTIVE WASTE MANAGEMENT POLICY DEVELOPMENT AND IMPLEMENTATION

This section provides a summary of the development and implementation history of radioactive waste management policy in the UK. In this respect it considers two principal periods: pre 1997 and post 1997.

In March of that year the Secretary of State for the Environment refused to give Nirex the go-ahead to construct an underground research facility at its preferred repository location of Sellafield – a decision which the House of Lords select Committee on Science and Technology said "stopped dead in its tracks" the UK programme for the deep disposal of radioactive waste [1].

This section also considers current decommissioning policy and the future implementation of policy following any change in policy.

2.1 Pre 1997

The first major Government review of radioactive waste management in the UK was carried out in the late 1950s but the next review did not take place until the 1970s when the Royal Commission on Environmental Pollution issued the "Flowers Report" [2].

As a result [3], the Government made the Department of the Environment responsible for radioactive waste management policy, increased HLW disposal research, but recognised the need for a national ILW disposal facility. A further consequence was the establishment of Radioactive Waste Management Advisory Committee (RWMAC) to provide independent advice to Government.

As part of the HLW programme, the drilling of boreholes began at Altnabreac, Scotland in 1979 and later at Harwell in Oxfordshire but was discontinued in 1981 as a result of public opposition.

A 1982 policy White Paper [4] acknowledged that the lack of ILW disposal facilities was a "major gap" and indicated the need to have one "by the end of the decade". The paper also announced the setting up of the Nuclear Industry Radioactive Waste Executive (i.e. NIREX) by the nuclear industry. NIREX, which was incorporated as United Kingdom Nirex Limited (Nirex) in 1985, had the remit to develop new land based facilities for LLW and ILW and run the annual sea dumping operation. No organisation had the responsibility to look at HLW (or spent nuclear fuel) disposal and the Government stated in the White Paper that HLW would be stored for about 50 years.

Sea disposal was halted in 1983 as a result of the meeting of international London Dumping Convention. The Government later announced it would keep open the option for disposal of large items of waste from decommissioning of nuclear plant, before eventually accepting a full ban.

In 1983, Nirex announced its choice of Elstow for a near-surface facility for LLW and short-lived ILW, and Billingham for a deep facility for long-lived ILW. Following much local opposition at Billingham, in January 1985 the Secretary of State for the Environment invited the Executive not to proceed further at Billingham and asked it to select further sites for investigation for shallow disposal [5]. In 1986 Nirex announced its choice of four sites: Killingholme, Fulbeck, Bradwell and Elstow.

In 1986 the House of Commons Select Committee on the Environment published "The Rossi Report" [6]. It concluded that the UK lagged behind other nations on geological disposal and recommended that near-surface disposal facilities would only be publicly acceptable for short-lived LLW. The Government accepted the recommendation [7] but noted there were no technical reasons behind this . They further reaffirmed the policy of storing HLW for 50 years and the commitment to develop a deep facility for long-lived ILW, saying that Nirex would identify potential sites.

In early 1987 Nirex and the Secretary of State for the Environment agreed that work on the four shallow sites be taken no further as there was not much cost difference between disposing of LLW with ILW in a deep repository and the cost of disposing of it in a new shallow repository. The Secretary of State announced in May 1987 that Nirex would concentrate on identifying a "suitable location for a deep multi-purpose facility" for both ILW and LLW marking the start of the deep repository site selection programme [8]. Nirex carried out this process in just less than two years eventually leading to the shortlisting of 12 sites. Nirex announced in 1989 its intention to investigate first Sellafield and Dounreay, an approach that was endorsed by the Government following consultation with RWMAC.

In the1990 White Paper, This Common Inheritance [9], the Government confirmed the choice of disposal in a deep repository as the long-term management option for ILW.

In 1991, Nirex announced that it proposed to concentrate its investigations on Sellafield because of the advantages it offered in terms of waste transport, with the majority of ILW for disposal arising from BNFL's operations at Sellafield.

In 1992 Nirex stated its intention to construct a Rock Characterisation Facility (RCF) (known in some countries as an underground rock laboratory or URL), submitting a planning application in July 1994. The application was refused by Cumbria County Council in December 1994, a decision which triggered the Public Inquiry into the RCF, held between September 1995 and February 1996.

Also in 1992 the Department of Environment published a policy statement [10] saying that “early disposal in a deep facility is the right answer” and “on-site storage is an unacceptable long-term option … because decisions on disposal should not be left to future generations…”.

A Government review of radioactive waste management policy was carried out in parallel with the 1994 commercial and economic review of nuclear power. The conclusions of this review were published in 1995 as Cm 2919 [11].

In summary, they were that the policy for radioactive waste management should be based on the same basic principles as apply to environment policy and sustainable development. Further, that radioactive wastes should not be unnecessarily created and are “disposed of at appropriate times and in appropriate ways so as to safeguard the interests of existing and future generations”. The conclusions also reaffirmed the policy of ILW disposal rather than indefinite storage.

Other relevant conclusions of the Review were that reprocessing should be a commercial judgment of the owner of the fuel; HLW and spent fuel (if not reprocessed) should be decay stored for 50 years prior to deep disposal and it would develop an HLW research strategy for this.

On Partitioning and Transmutation it would keep just a watching brief. Further, decommissioning of nuclear power stations should be undertaken as soon as reasonably practicable and that segregated funds should be established by the privatised nuclear industry, whilst it would examine the provisioning policies of the unprivatised industry.

2.2 Post 1997

In November 1996, the RCF Public Inquiry Inspector issued his recommendation on Nirex’s appeal to the Secretary of State for the Environment. In March 1997 the Secretary of State announced that he supported the Inspector's recommendation [12] that the appeal be dismissed.

The Inspector's grounds for recommending dismissal of the appeal concerned straightforward planning matters, which might apply to any type of development; and reasons particular to the RCF and to the repository which might have followed it. The planning matters included the adverse environmental impact of the development. He also stated that the proposal to build the RCF was premature as more needed to be known about the hydrogeology and geology of the site and the underground impact of constructing the RCF. The Inspector also concluded that the site had not been selected in an objective and methodical manner.

Active public debate on issues surrounding the decision took place in the aftermath of the 1997 announcement. Perhaps the most significant initial step was the House of Lords' Select Committee Enquiry [1]. They said the decision "stopped dead in its tracks" the UK programme for the deep disposal of radioactive waste. Their report made some 14 recommendations including: the need for a fully comprehensive policy for all nuclear waste; co-ordination of all UK research; the site selection process; the need for a clear policy for the UK's stock of separated plutonium; waste substitution; and that the Government should act without delay noting that "the programme for repository development is a long one and cannot be rushed …".

Following the publication of the House of Lords' Select Committee report, a Consensus Conference of "informed citizens" was held in London in May 1999 [13]. They concluded, *inter alia*, that radioactive waste must be stored underground in a monitorable and retrievable way regardless of cost; a neutral body should deal with waste management; the criteria for site selection should be open and publicised; decision making must be open and transparent; nuclear power should not be expanded until a way is found to deal adequately with the waste.

In October 1999 the Government gave its initial response to the House of Lords Select Committee's report [14]. One major aspect of that response was that the Department of Environment Transport and the Regions (DETR) announced that a Government consultation would be established. The consultation paper (Managing Radioactive Waste Safely "MRWS") was issued in September 2001 [15] by the new Department of Environment, Food and Rural Affairs (DEFRA, now "Defra") and the Devolved Administrations[i]. A key point was that whilst previous policy (and indeed the House of Lords' report) centred on disposal as the long-term radioactive waste management option, the consultation paper assumed that all options would be under consideration.

In April 2005, the Nuclear Decommissioning Authority (NDA), a non-departmental Government body, was formally established under the 2004 Energy Act, with the task decommissioning and cleaning up nuclear sites. At the same time Nirex was made independent of the nuclear industry through a Ministerial decision. Its shares, previously held by UKAEA, BNFL and British Energy, transferred to a Company Limited by Guarantee, jointly owned by Defra and DTI. Under the arrangements Nirex remains independent of and separate from the NDA, but its funding comes through a funding agreement between the two parties.

2.3 Decommissioning policy

When each of the UK's operational nuclear power stations and other nuclear facilities come to the end of their operational life they have to be decommissioned. Over a period of time (which may be several decades) the plant will be dismantled and

[i] Note that long-term radioactive waste management is a devolved issues. Therefore the MRWS programme is a joint undertaking by Defra, the Scottish Executive, the Department of the Environment of the Northern Ireland Assembly and the Welsh Assembly.

radioactive waste will be removed and managed in a staged process, leading to the eventual demolition of the plant and site clearance to an agreed end-state.
The policy of the Government and Devolved Administrations [16] was published in September 2004 and replaces that given in Cm 2919. Some key points of the policy are that:

- Decommissioning should be carried out as soon as reasonably practicable taking all relevant factors into account (including knowledge and skills) on a case-by-case basis;
- Each nuclear site operator is expected to produce and maintain decommissioning strategies and plans which will be reviewed by the Regulators every 5 years, take into account the views of local stakeholders and the proposed future use of the site;
- The plans should be presented in a transparent way and take account of safety, security, waste minimisation through Best Practicable Means (BPM), environmental impact, resources etc.;
- The site's end-state and future use should be considered along with the wishes of the local community. An overriding consideration will be whether it represents the "Best Practicable Environmental Option" (BPEO);
- Consideration needs to be given to the policy development under the MRWS programme and avoid waste creation of forms that would foreclose future management options;
- If possible waste should not be created until there is a management route, but [it is recognised] that some waste will need to be packaged for storage rather than disposal and in a manner which does not preclude disposal. This should be done in accordance with the regulatory arrangements for the conditioning of ILW and the Nirex Letter of Comfort system (see Section 3.3.1);
- Radioactive discharges to the environment should reflect application of ALARA (As low as reasonably achievable) and BPM principles;
- Operators are expected to ensure that decommissioning is adequately funded, noting that the NDA will be funded directly by the Government;
- Under BE's restructuring plan they will pay into the Nuclear Liabilities Fund (NLF) to cover their decommissioning costs. The fund will be underwritten by Government[ii].
- The Government are committed to ensure that the application of regulatory controls is transparent, the key parts of which are the site licence and discharge authorisations, and the requirements of the Nuclear Reactors (Environment Impact Assessment for Decommissioning) Regulations 1999;
- Operators should maintain the knowledge base and skills necessary for decommissioning and waste management;
- New facilities should be designed and built so as to minimise decommissioning wastes and costs, thus minimising the liabilities for future generations.

2.4 The MRWS programme

2.4.1 General

The Government responded to the House of Lords Select Committee report in October 1999, and recognized the need for a period of reflection [17] and detailed their intention to consult widely on the issues arising. The Government confirmed the need for openness and transparency in its approach. As a result the Managing Radioactive Waste Safely ("MRWS") programme was launched in September 2001 [].

An initial consultation posed questions on:

- The size and scale of the problem;

[ii] Note: the NDA draft strategy document indicates that they, on behalf of DTI, oversee BE's decommissioning plans.

- How the views of the public will contribute to the policy making process;
- Any organisational changes needed to ensure that a sound policy is chosen and implemented;
- The programme for the development and implementation of policy.

The Government recognised the need to "inspire public confidence" in future decisions on policy development and proposed to set up an independent authoritative body (which became CoRWM) to advise it on information requirements for future decision making on options.

A proposed "rough guide" five-stage programme was set out for "illustrative purposes" in the MRWS document. Following initial consultation it was amended to a four-stage process. The programme has also slipped by about six months and the amended timetable is shown in Table 1.

The Government acknowledged that the shape and speed of the programme was dependant on many factors but said "we must press ahead as quickly as we can. But we must also get the decisions right, and ensure that the strategy wins public confidence".

The MRWS paper also recognised that issues other than process needed to be addressed:

- the principle of segregating UK waste types by half-lives;
- management of spent sealed sources;
- the link between waste substitution and the availability of a repository or other facility;
- the general approach to decommissioning, recognising the lack of a national disposal facility;
- consideration of the UK stockpile of plutonium, including whether some (other than for "minimal" defence requirements) should be declared a waste or be regarded as a potential resource through MOX fuel fabrication; and
- consideration of the long-term management of uranium, including whether some proportion should be declared as waste; again the issue is determining between waste and resource

The first stage of the consultation was completed in March 2002 and in order to oversee Stage 2 the Committee on Radioactive Waste Management (CoRWM) was established in November 2003 as an independent review body to oversee the evaluation of long-term waste management options and to make recommendations to Government.

Note that with regard to LLW, the policy is for near surface disposal at the National Low Level Waste Repository at Drigg, Cumbria. Defra and the Devolved Administrations are currently implementing a consultation programme looking at the future policy for the management of LLW, which has been established in recognition of the fact that future LLW arising, e.g. from decommissioning nuclear power stations, is expected to exceed the existing capacity of the National LLW disposal facility. This will also consider how to give extra flexibility to deal with the wide-ranging wastes, including very low level wastes. Such LLW also has to be managed in the long-term, although in this area, in contrast to higher activity radioactive waste, the key issue is how best to do this using a range of solutions which already exist.

2.4.2 CoRWM and options

In creating CoRWM the Government acknowledged that even if no new nuclear plants are built, the country still has a substantial nuclear legacy. The options for dealing with some 500,000 tonnes (te) of higher activity waste, which will arise over the next hundred years, will include consideration of underground disposal and surface storage. CoRWM's main focus is on the UK's high and intermediate level waste; there is a separate Government review for management options for low-level waste. As a result of the creation of CoRWM, the Radioactive Waste Management Advisory Committee (RWMAC) was suspended.

CoRWM is an independent committee appointed jointly by the UK Government and Devolved Administrations to oversee a review of options and to recommend the option, or combination of options, that can provide a long-term radioactive waste management solution. Details of the Committee's workings, membership details etc. can be found on its website www.corwm.org.uk. Note that CoRWM was not asked in its terms of reference to consider new build, but it recognised that if it was to address stakeholder concerns during its process, the issue was unavoidable.

CoRWM was asked to ensure that the review of options was carried out in an open, transparent and inclusive manner, engaging members of the UK public and key stakeholders, and providing them with the opportunity to express their views. It is explicitly not considering potential sites as part of its work, but is considering generic issues that could affect the siting process. CoRWM will make recommendations to the Government in July 2006 but will publish its initial findings in April 2006.

Notably, CoRWM was specifically asked to consider all options starting with a "blank sheet of paper", and to eliminate as soon as practicable those which stood no realistic chance of implementation. CoRWM and the MRWS programme in general has come under some criticism, notably by the House of Lords Science and Technology Select Committee [18]. They criticised, *inter alia*, the "blank sheet of paper" approach and the make-up of the Committee. They also said that "The Government must no longer allow delays in developing a long-term radioactive waste management strategy to be used as a pretext for deferring decisions on the future of nuclear power".

In July 2005, CoRWM short-listed the following options for detailed assessment (see schematic diagrams in Figure 1):

1 Long term interim storage and its variants:
  - Local to current waste location, above ground, protected (e.g. from "9/11" style attack);
  - Local, above ground, unprotected;
  - Local, below ground, protected;
  - Centralised, above ground, protected;
  - Centralised, above ground, unprotected;
  - Centralised, below ground, protected;

2 Deep geological disposal:
  - Deep disposal;
  - Disposal in boreholes;

3 Phased deep geological disposal (the Nirex approach);

4 Non geological disposal[iii] (near surface) for reactor decommissioning wastes only:
  - Near surface engineered vault, local to current wastes, protected;
  - Near surface engineered vault, centralised, protected;
  - Mounded over reactors;
  - "Forsmark" (as in Sweden) type vault (shallow, less than 100m) disposal, centralised;
  - "Forsmark" type vault (shallow, less than 100m) disposal, local;

[iii] If this option was implemented. In addition, other options would be required for the other waste streams.

2.4.3 Option selection and societal implications

Introduction

The disposal options are the only "permanent" waste management options being discussed by CoRWM. The storage options are not permanent solutions, and are only being considered for up to 300 years. The length of time that active management of a facility would need to be maintained will depend on the option chosen and the way it is implemented. For example, if indefinite storage was implemented, active management will be required for hundreds of thousands of years. If disposal is implemented it could take about a hundred years to construct the facility, emplace all the radioactive wastes and then backfill and close the facility. If a phased approach to disposal is chosen the facility could be maintained as an underground store for several hundred years before being closed.

The longevity of human organisations or civilisations and likelihood of societal collapse is therefore a factor to be considered when assessing the options. Nirex undertook a study [19] to outline examples of societies, organisations and archives that have been maintained and/or lost and some implications this may have for long-term radioactive waste management. The following paragraphs summarise the findings and conclusions. In summary, a range of factors were identified in the study as being important for the survival or loss of civilisations, organisations and objects. It was found that survival is strongly influenced by the wider context, or chance, or being in the right place at the right time.

Survival of civilisations and organisations

In the study no examples were found of societies or organisations existing over timescales that radioactive waste will remain hazardous (i.e. hundreds of thousands of years). Therefore, it does not appear to be possible to rely on an organisation or society to manage radioactive waste over these timescales.

Survival of information

Long-term radioactive waste management will rely on the preservation and transfer of information and is a major consideration by radioactive waste management organisations worldwide and by the IAEA. The study showed that the management system is more important for survival than the media used, and showed that the greatest threat to information transfer will be institutional change.

External events

The study gave examples of a number of external events that could influence stability, such as wars, collapses of civilisation and climate change. However, it cautioned that it was the more 'trivial' causes that could lead to problems, such as the destruction of archives by paper decay.

The examples were:

- Climate change has brought about civilisation collapse in the past for example, the Vikings. Current climate change will be a major threat to global stability, causing conflict and chaos.
- Disease, and overuse of resources have caused civilisation collapse in for example Easter Island. Water is an increasingly scarce resource and is thought to be a likely cause of future major conflict. Disease, such as avian influenza, is a continuing threat to civilisation through pandemic.
- The UK is currently dependent on trade links with other countries and even if it were safe from collapse due to its advanced technology, collapse in more vulnerable could have a major impact here.
- A natural disaster (tsunami, hurricane) can turn possibly the most developed, complex society into a scene of anarchy and starvation, with loss of institutional control, in a matter of hours.

In the case of a radioactive waste management facility that requires ongoing management, the time collapse takes, from the first warnings to the end would be extremely important, as would understanding and acting upon the earliest warning signs. The report concluded that if a management option requiring long-term societal control were to be implemented, it might be instructive to consider what, if any, consistent warning signals exist.

Resources

Long-term radioactive waste management will require skills and funding over the time period when active maintenance of the facility is required.

- Skills and personnel loss in the nuclear field has already occurred following the collapse of the USSR and is already a concern in the UK nuclear industry.
- Funding continuity for long-term radioactive management is important if the facility requires active maintenance over thousands of years. To fulfil the principle of intergenerational equity, the financial burden of waste produced by our generation must not be passed on to future generations. However, even if the money were invested now to be used in the future the likelihood of a bank surviving over the timescales involved is low and it is possible that this basic ethical principle can not be fulfilled.

2.4.4 Post CoRWM and future policy implementation

CoRWM will make its recommendation to Government in its final form in July 2006. Stage 2 of the MRWS programme will end with an announcement by Government on whether to accept, reject, or otherwise take on board that recommendation (possibly by the end of 2006). Stage 3 will be a consultation on implementation of the chosen policy. If needed, new legislation setting out the implementation programme will be put in place at the start of Stage 4.

In the MRWS document, the Government indicated that the Stage 3 consultation should consider the site selection process. The failures of the past site selection processes in summary include the HLW programme of the 1970's, the initial shallow and deep siting programmes which ended in 1987, and finally, the deep repository programme which ended at Sellafield in 1997. However, it is important to note the context for the past site selection exercises and how this would be different if siting of a deep geological repository (or other centralised facility, or even a new nuclear power station) were to be considered again under the Government's MRWS consultation process. The following paragraphs summarise the main changes that have taken place since the previous site selection process and how they could affect a future site selection process. Input here includes work done by Nirex to review the last site selection programme [[20]].

The repository concept

The repository concept under consideration in the last siting exercise was based on one intended to be backfilled and sealed as soon as possible after waste emplacement. In response to extensive stakeholder demands, Nirex has since developed the Phased Geological Repository Concept which is one of the options being considered by CoRWM (see also section 3.3.2). This allows the monitoring of the waste in underground storage for up to several hundred years until society takes the decision to backfill, seal and close the repository or manage the waste in some other way.

There has also been a significant amount of repository research in the UK and overseas such that the understanding of a host site's requirement has been refined which may affect the geological characteristics that would be sought for potential sites.

Stakeholder involvement in the site selection process

The lessons learned from the failure of the previous site selection process will undoubtedly be applied in any future site selection process, to ensure that it is open, transparent and inclusive and that there is stakeholder involvement and influence. As implied above, Stage 3 may not begin to consider a new site selection process until 2007/8. Therefore, a number of aspects could be different in any future site selection process to encourage and ensure greater stakeholder involvement, including how local community and other stakeholders are involved, site evaluation criteria and their relative weights (which would need to be agreed before the site selection phase itself); the ability to volunteer and the power to veto siting decisions, and community benefits.

The volume and types of waste being considered

The volume of intermediate-level waste and low-level waste under consideration in the 1980s totalled two million cubic metres. The volume of waste under consideration now is significantly smaller. The Nirex note indicated that under the 2001 Inventory assumptions, the total volume to be emplaced in a repository (if that were the chosen option) would be 237,000m^3 of ILW and 15,000m^3, of LLW. The latest 2004 assumptions would, of course, revise these estimates further (see section 3.2). The decrease in estimated volumes is due to taking account only of committed LLW and

ILW, rather than also projected volumes under various scenarios and the routing of all but a small volume of LLW to Drigg.

In addition, no consideration was given historically to HLW, spent fuel and other materials not yet declared as wastes such as plutonium and uranium. These wastes could also be considered for inclusion in the repository concept. These changes will affect the size of the repository, and therefore the size of the site that is required and also the geological requirements of the site. (See also section 3.3.2).

Advances in understanding

The UK's geology has, of course, not changed over the past 20 years, but the ability to investigate and model deep geology and the understanding of deep geological processes has improved significantly. Therefore, there are more favourable indicators of geological suitability, in addition to those recognised previously.

Improved surveying methods as used in the French and Swiss radioactive waste management programmes could bring in geological settings that were previously viewed as difficult to investigate. Major advances in computer technology mean that geological settings previously excluded as 'too complex to model' could now be considered and produce different results when screening sites against geological criteria. Also there is an improved understanding of the geological barrier which together with a better understanding of relevant geological processes means that different geological settings could now be included or excluded.

Legislative developments

The Aarhus Convention [[21]] came into force in 2001. It aims to protect and improve the environment and ensure sustainable and environmentally sound development. The convention aims to allow public access to information, enable citizen participation in decisions, give them access to environmental justice with provision of assistance to exercise their rights, increase accountability and transparency in decision making and increase public support forn decisions.

The requirements of the Aarhus Convention are transposed in UK legalisation [[22]] that implements the European Union's Strategic Environmental Assessment Directive [[23]] (see also guidance published by the Office of the Deputy Prime Minister, [[24]]) and the Environmental Impact Assessment Directive [[25]]. Sustainability appraisals also have to be undertaken for developments in the UK [[26]] to ensure the social, environmental and economic impacts of proposals are assessed and mitigated if possible.

Together these pieces of legislation make stakeholder involvement in the early stages of a decision-making process compulsory, they give stakeholders the right to influence the scope of the assessments to be undertaken and the decision-making process itself.

Stepwise decision-making

International experience [27, 28, 29, 30] shows that EIA and SEA can be used to:

- Engage stakeholders in dialogue about a long-term solution to radioactive waste and structure the work undertaken;
- Define and communicate the scientific and technical work;
- Integrate scientific and social research on radioactive waste management into the decision-making process; and
- Encourage and enable stakeholder involvement in the decision-making process.

Research [31, 32, 33, 34] has shown that a stepwise approach to decision-making regarding long-term radioactive waste management is important because it:

- Enables flexibility to be built into the process;
- Provides clear decision points;
- Enhances stakeholder involvement, transparency and auditability;
- Enables steps to be reversed if necessary.

SEA and EIA provide frameworks with clearly defined steps. Therefore, they could be used to structure the decision-making process relating to long-term radioactive waste management in the UK. Moreover, a Sustainability Appraisal (SA) could be undertaken to ensure that all the relevant issues are addressed. The UK guidance on Sustainability Appraisal [26] aims to align the requirements of SA and SEA in a single assessment. Both processes have similar stages, but Sustainability Appraisal considers social and economic as well as environmental issues.

Siting has been seen as the most controversial and difficult stage in developing a long-term radioactive waste management facility. Therefore, it is important that the process of site investigation and selection is seen as legitimate and has stakeholder support. Nirex believes that the site selection process should be structured using the SEA and EIA frameworks as outlined in Figure 2.

UK Guidance on SEA outlines the stages in the process as follows can be mapped onto the decision-making process for identifying a short-list of potential sites as outlined in Table 2. The steps involved in an EIA are outlined in a European Commission Report on EIA and geological repositories [27] can be mapped onto the process for recommending a preferred site as shown in Table 3. Working groups could be set up in potential host communities to enable the local community to scrutinise the work of the implementer and make inputs into the decision-making process. Mechanisms similar to those used in Belgium [35] and Sweden [36] could be used and funding for these would need to be provided.

To provide provisioning advice to radioactive waste producers, Nirex has developed a baseline programme that outlines the stages needed to implemented a deep geological repository and estimates of how long that would take. It is estimated that a site could be selected for underground research by 2020 and a repository could be available by 2040. The Finnish experience, outlined in section 4.7.4, indicates some 18 years to get to a final site choice.

The NDA has called for a repository to be available by 2025 to allow their plans for reactor decommissioning in 25 years to be delivered. Even if CoRWM were to recommend a form of geological disposal as its preferred option, and this becomes UK policy, it is unlikely that a permanent solution to long-term waste management will be available on the NDA timescale. This is due to the necessary siting, R&D, planning and construction programmes which must be implemented, including the necessary legislative requirements as outlined above. The repository siting programme would be more than just a scientific exercise, it would involve an important social and ethical dimension and stakeholder interaction. As such, 2025 may not be unachievable if due process leads to a willing host community coming forward, and that the overall progress is at the speed desired by stakeholders, rather than that desired by the nuclear industry.

3 RADIOACTIVE WASTE MANAGEMENT IN PRACTICE

3.1 General

Radioactive waste is generated in the UK by a range of nuclear and non-nuclear activities. Waste has been generated and continues to be generated from nuclear power generation, spent fuel reprocessing, research, industrial and military programmes. Further, wastes will also result from future decommissioning of nuclear facilities. The waste itself contains a wide range of levels of radioactivity (see Box 1 [[37]]).

Wastes are currently stored in interim storage facilities on regulated nuclear sites over the short and medium term (of the order decades). The HSE expects nuclear site licensees to manage radioactive waste such that it is compatible with future potential disposal options, and unless justified on safety grounds, does not foreclose foreseeable management options. A Nirex "Letter of Compliance" issued for a particular processed waste form and packaging is an important part of this demonstration. This system has developed since the late 1980's and has been used to judge the acceptability of all intermediate level waste packages produced in the UK.

There are a number of "unconditioned" waste streams (legacy wastes which are not in a passively safe form), particularly at the Sellafield reprocessing site, which are stored in facilities that whilst considered acceptable at the time, now pose a number of significant challenges with respect to management and decommissioning of the facilities – see Box 1 [[38]].

3.2 Inventory of radioactive materials

3.2.1 Radioactive waste

Defra and Nirex periodically publish an inventory of radioactive waste in the UK. This inventory provides a reference source of information for Government and its agencies, Nirex, and others with a role or interest in the management of radioactive waste. The latest version considers stocks of wastes in store and predicted to arise in the future under current plans as at April 2004 and was published in October 2005 [[39]].

The report includes all the higher activity materials which have been declared as wastes. For a discussion on material not yet declared as wastes see the next section. As reported in the 2004 Inventory, the total volume of radioactive waste that exists today and is forecast to arise in the future is 2.3 million m^3, comprising 2.1 million m^3 of LLW (mainly unconditioned); 220,000m^3 of ILW and 1,300m^3 of vitrified HLW. Note the ILW volume of 220,000m^3 is a combination of conditioned waste in stock and future arisings; the estimated final conditioned volume is 240,000m^3.

A further 1 million m^3 has already been produced and disposed of. This is primarily LLW disposed of at Drigg and Dounreay, but includes a small amount of ILW disposed of at sea. Under existing scenarios about 95% (2.2 million m^3) of the radioactive waste total already exists and is being held in stores as noted above, but much of it, 1.6 million m^3, will arise as waste when facilities are decommissioned.

The other 5% (100,000m^3) of the total has yet to be produced and is that forecast from the future planned nuclear operations (not including decommissioning which is covered in the "existing" total), ongoing defence programmes and continued use of radioactivity for medical and industrial purposes. The volumes referred to assume the following scenario:

- Nuclear power stations
  - Remaining operational power stations shut down over the period from 2006 to 2035;
  - No new nuclear power stations are constructed;
  - Main reactor structures left on site for about 100 years before final site clearance;
- Spent fuel reprocessing continues until financial year 2012/13;
- The Joint European Torus fusion experiment shuts down in 2006;
- Defence:
  - A continuing nuclear defence capability to 2040;
  - A continuing nuclear-powered submarine programme to 2100
- Medical and industrial sources usage continues as today.

3.2.2 Other radioactive materials and VLLW

Spent nuclear fuel, plutonium and uranium are not currently classified as wastes due to their potential use as resource, but they too also require safely managing pending availability of a long-term management route. CoRWM are addressing this subject as part of their programme. Spent nuclear fuel from the UK's Magnox and AGR nuclear power stations is transported to Sellafield for reprocessing, where the waste products (HLW, ILW) are stored in interim storage facilities; LLW arisings are consigned to Drigg. Spent fuel is stored in ponds where the water provides both shielding and cooling. The separated plutonium and uranium arising from reprocessing is also stored. Spent nuclear fuel from Sizewell B PWR power station is not reprocessed and is stored in storage ponds.

In 2003 Nirex undertook a study [[40]] to look at what additional materials there were which could be declared as radioactive wastes. The report identified volumes of wastes not included in the Inventory reference case as described above. A summary of the findings of that report, updated as appropriate was presented in Nirex report N/122 [[41]] and has been used to provide the information below.

Plutonium

Plutonium is a radioactive element created as a by-product in nuclear reactors. It can be separated from nuclear fuel by reprocessing. Separated plutonium can be used as a nuclear fuel and in nuclear weapons.

There are currently 93te of separated plutonium in the UK, most of this material is held in store at Sellafield in oxide form as a powder. A small quantity may be returned to overseas countries. Some plutonium is held for military purposes. The total quantity of separated plutonium will increase to approximately 140te under current reprocessing assumptions. In addition there is plutonium within spent fuel. For more discussion on the plutonium issue, see the next section.

Uranium

Uranium is a radioactive element that occurs in natural form as an ore which is mined and can be used for the manufacture of nuclear fuel and nuclear weapons. It is also a by-product of spent fuel reprocessing. Less radioactive uranium (called depleted uranium) has more commonplace uses, such as counterweights in aircraft. Most uranium is stored either as gaseous uranium hexafluoride or as an oxide powder.

There are currently 100,000te of separated uranium held in a number of stores, principally at Springfields, stored in a number of forms including powder. A small quantity may be returned to overseas countries. Some uranium is held for military purposes. The total quantity of separated uranium will increase to approximately

150,000te under current reprocessing assumptions. In addition there is uranium within spent fuel.

Spent fuel

Spent nuclear fuel is fuel that has been irradiated in a nuclear reactor. By activity content it comprises 1% Pu, 96% U and 3% fission products. It can be reprocessed (to separate out plutonium and "unburnt" uranium) or managed in some other way. Like HLW, spent nuclear fuel is intensely radioactive and generates heat. It usually comprises uranium oxide, and contains fission products.

Approximately 5,000te of UK spent nuclear fuel is currently held in stores at Sellafield, Dounreay and a number of reactor sites. Some of this fuel is planned to be reprocessed. There will also be more spent fuel generated from continued power generation. Under current plans it is estimated that 4,700te of spent fuel will not be reprocessed.

Contaminated land

Estimates of land contaminated with radioactivity have been made but are very uncertain. RWMAC [[42]] estimated the total amount in the UK to be of the order of 18 million m^3 (equivalent to 36 million te) of unconditioned material. Most of it is at Sellafield, Dounreay and Aldermaston.

Radioactive sources

Approximately 10,000 sources are in use in the UK now, mainly for medical and industrial purposes. Most of these are returned to the manufacturers after use. Record keeping in this area has often been poor, resulting in the loss of sources. Radioactive sources exist in a wide variety of forms, from small metallic objects to gases and liquids.

VLLW

Small quantities of waste can be routinely disposed of to domestic landfills. There are approximately 5 such sites in use in UK. VLLW may be lightly contaminated miscellaneous items such as laboratory equipment, gloves and medical wastes.

Miscellaneous

Some organisations have disposed of radioactive waste under other arrangements, either on a nuclear licensed site or local tips (estimated to be 10,000m^3), or (before it was banned) in the sea (33,000m^3).

Some radioactive waste can be incinerated either at purpose built incinerators located on nuclear sites or domestic incinerators.

All nuclear facilities may discharge radioactivity to the environment via liquid and aerial effluents under strictly controlled authorisations set by the UK regulators.

3.2.3 Issues surrounding plutonium

Plutonium is currently classed by the nuclear industry [[50]] as an asset with zero value, and not as a waste. UK-owned civil plutonium stocks have been created through the reprocessing of spent nuclear fuel with the original intention of re-using this material in a future fast breeder reactor programme.

It was believed in the 1950s and 1960s that a "closed" nuclear fuel cycle was the most desirable option for future energy supply. Fuel from nuclear reactors would be reprocessed after first use and the recovered plutonium would be recycled as fuel in fast breeder reactors. The fast breeder reactors would produce more plutonium, which could fuel other types of reactors.

The UK fast breeder reactor programme, was however, formally cancelled in the early 1990's, closing this option for the use of plutonium, as the predicted uranium shortages did not occur. As a result, significant stockpiles of plutonium have arisen as a result of reprocessing operations.

Suggestions have been made that plutonium should be classified as a waste and disposed of appropriately, rather than used as a future fuel. This issue is complex and may need to be addressed in any decision regarding new build in its potential use as MOX fuel (see section 5.6). The NDA has declared that reclassifying plutonium as a waste would add several billions of pounds to the total cost of dealing with the UK's nuclear legacy. The NDA is planning to discuss with Government what proportion of plutonium should be regarded as a strategic stock, which could be used as a potential future energy source, leaving the remainder as waste. Further details of the implications of reclassifying plutonium as a waste can be seen in references [43] and [44].

CoRWM's position paper on plutonium [45] notes that plutonium storage arrangements at Sellafield are satisfactory for the immediate future (approximately 25 years). They are only viewed as an interim measure for two reasons:

- The storage of plutonium dioxide powder cannot be considered as 'passively safe'. There are maintenance and monitoring requirements. Human intervention Is required to maintain safety.
- There is increasing international pressure to reduce stockpiles of separated plutonium.

If plutonium were to be classified as a waste, for security reasons it would need immobilizing in a stable wasteform, suitable for long-term management, and does not necessarily discount recycling options in the future, although it is recognised that immobilisation would make recycling much more difficult. Immobilised plutonium, however, would require additional processing steps to enable its re-extraction.

Two of the aims of immobilisation are:

- Proliferation resistance: the plutonium is rendered unattractive to any potential illegal use, for example, as the nuclear explosive in an atomic device or radioactive 'dirty' bomb.
- Disposability: the plutonium will be conditioned in an acceptable way for possible disposal.

There are a range of different immobilization methods, including cementation, vitrification and ceramification, which are described in more detail in the CoRWM position paper.

3.2.4 Scenario variations

CoRWM established a baseline inventory of radioactive wastes and materials on which it will make its recommendations [46]. As acknowledged in the reference, this was principally derived from the draft 2004 Inventory data and whilst some of the underpinning data may have been modified in the move to the final version, this is not expected to materially affect either this analysis or conclusions.

CoRWM made the following principal assumptions.

Nuclear power reactors:

- All operating Magnox reactors are shut down by 2010;
- AGRs operate for up to 35 years, with the last shutdown in 2023;
- Sizewell B PWR operates for 40 years and is shutdown in 2035;
- No new nuclear power reactors are constructed.

Spent fuel reprocessed:

- All Magnox fuel (55,000tU);
- AGR fuel covered by existing contracts (5,000tU);
- Overseas LWR fuel covered by existing contracts (4,500tU);
- Return of overseas Pu, U and HLW, with ILW & LLW substitution.

Radioactive materials if these are to be managed as wastes:

- All UK stockpile of separated plutonium (102te);
- All UK stockpile of uranium (153,000te);

- AGR fuel not covered by existing reprocessing contracts (3,500tU);
- Sizewell B PWR fuel (1,200tU).
- All radioactive wastes, including spent fuel, are packaged so that they are in a form suitable for long-term management.

The baseline inventory includes all wastes both in existence and forecast to arise in the future (from e.g. decommissioning). Their baseline volume was 477,860m^3 as indicated below. [Note, care should be taken in comparing these figures, which represent packaged volumes, with the ones in the previous section.] CoRWM further considered changes in the above assumptions to the baseline scenario as follows:

- The building of new nuclear power reactors (discussed in more detail later in section 5.1);
- The quantity of spent fuel reprocessed;
- ILW and LLW substitution (return additional HLW in place of ILW from reprocessing overseas spent fuel);
- Lifetimes of existing nuclear power reactors;
- Decay storage and decontamination of ILW (for disposal as LLW);
- Early decommissioning of nuclear power reactors;
- Waste segregation (of short-lived ILW; of mixed ILW/LLW streams);
- Quantity of unaccounted spent sealed radiation sources (SSRSs).

They concluded the potential for changes (+/-) in the baseline volume of 477,860m^3 for various scenarios on spent fuel, HLW,ILW, plutonium, uranium and LLW could be as shown in the following table which has been adapted from their inventory summary document – see Table 4. Volume and activity comparisons are summarised in section 5.3.

Regarding non-Drigg LLW, baseline volume 37,200m^3, CoRWM noted that the nature of most of the waste - activated reactor core graphite – would make it difficult to treat in order that it would be acceptable for disposal to Drigg. There may be some uncertainty in the relative quantities of ILW and LLW reactor graphite, but this will not affect the inventory.

3.3 Waste packaging and storage

3.3.1 The letter of compliance process

Prior to the Government making any decision on future radioactive waste management policy, they and the regulators have deemed it appropriate that unconditioned and decommissioning ILW should continue to be packaged under the Nirex Letter of Compliance (LoC) system. Endorsement of this process during the period for which CoRWM is deliberating was given by the Governments cross-Government Radioactive Waste Management Policy Group, which noted that the LoC process gave a good level of compatibility with the likely options being considered by CoRWM, and that packaging should not be delayed during the review of options.

Since it was established in 1982 the Nirex role has included development of ILW waste package standards and specifications necessary to produce waste packages compatible with a planned repository.

Since the mid-1980s, many waste producers have invested in conditioning and packaging plants to process waste immediately after creation and to treat initiate retrieval of historic legacy wastes, using the standards and specifications to guide their development. Through issuing a Letter of Compliance ("LoC", originally "Letter of Comfort") Nirex indicated when the proposed waste packages were compatible with the disposal concept being developed.

In January 2004 improved arrangements were introduced by the regulators [47] requiring that safety cases covering the ILW conditioning plants also address the disposability of the waste packages. The LoC assessment is seen as the primary means of obtaining the safety case. This change gives increased confidence to regulators and other stakeholders that the long-term management of waste packages is considered before they are manufactured. The process comes under the regulatory scrutiny of the Environment Agency of England and Wales (EA), and its counterpart in Scotland, the Scottish Environment Protection Agency (SEPA) which advises the Nuclear Installations Inspectorate (NII) on waste package disposability.

As noted earlier, the revised arrangements are also recognised within the Government's updated policy on decommissioning of UK nuclear facilities issued in September 2004 . The policy update confirms that operators should continue to process decommissioning wastes in accordance with Nirex LoC arrangements.

In March 2005, NII, EA and SEPA issued "Guidance to Industry" [[48]] on the operation of the improved arrangements requiring that site operators set out the strategy for retrieving, conditioning, storage and ultimate disposal of wastes. The ILW Conditioning Proposal is required to justify the selected packaging option based on consideration of BPEO (Best Practicable Environmental Option) and BPM (Best Practicable Means) and a disposability case as described previously.

3.3.2 Repository concept

A fundamental principle of the LoC system is that in the absence of a repository, and thus the absence of waste acceptance criteria, there is still a repository concept against which the disposability of ILW packaging proposals can be assessed. Part of the Nirex remit since its inception has therefore involved the development of the repository concept. This has evolved over the years to take account of changing waste volumes and other factors, principally the inclusion of monitoring and retrievabilty, to what is now described as the Phased Geological Repository Concept (PGRC). This is described in more detail in Nirex Report N/122, [41] referred to earlier, and in Nirex Report N/074 [[49]].

In summary, the PGRC is a multi-barrier system comprising physical, chemical and geological barriers to ensure any radioactivity that returns to the human environment in the future is within acceptable levels (see The phased geological repository concept). Retrievability is a component part of the concept, as mentioned, and is achieved initially by operating the facility as a retrievable store in which the wastes can be maintained and if necessary retrieved. Decisions about how and if to proceed towards closure of the facility are offered to future generations without placing an undue burden on them. See Figure 3: The phased geological repository concept.

Note that this concept is only for ILW and LLW not suitable for Drigg. With the encouragement of Government, Nirex has developed a repository concept for HLW and spent fuel. This is based on the Swedish KBS-3 concept as being implemented in both Sweden and Finland. Again this is described in more detail in Nirex Report N/122 [41]. In addition Nirex is investigating the disposability of other materials such as separated stock of plutonium and uranium, and spent fuel from submarines and research reactors.

3.3.3 Waste storage

Interim storage is the status quo in the UK and it is the first stage of a long-term management strategy. In principle, there is a difference in the more recent design of stores (which take packaged wastes) that anticipate that a disposal option will be implemented in some tens of years, and historical stores (which were for untreated waste) whose lifetime represented the longest that technology could then achieve.

Currently, HLW and ILW are stored in interim storage facilities at their sites of origin. There are several types of interim stores in use. These range from historical facilities built in the 1950's and 60's at, for example Sellafield, for which plans are now being drawn up to empty, treat and package the wastes and decommission, to more recent purpose built facilities, built in the last decade for packaged wastes. The design life for these newer facilities is of the order 50 years, although it may be possible to extend their lifetime to 100 years given appropriate maintenance.

3.4 Decommissioning

3.4.1 General

As noted above, the NDA are responsible for the decommissioning of nuclear facilities which in terms of civilian reactors currently applies to the Magnox fleet. The NDA has produced a draft strategy for consultation [50] for which the consultation period closed in November 2005. Although not published, the NDA had to submit the (revised) draft strategy following the consultation to Ministers by mid-December 2005 for which the Government must give its approval by the end of March 2006.

The strategy document notes there are at least three main approaches to decommissioning reactor sites:

1. The current approach is based on Government policy and the five-yearly review process:
   - ➢ This strategy is based on a period 20 to 25 year period during which ancillary buildings are cleared an the reactor(s) placed into a care and maintenance regime. This would include for example construction of an interim ILW storage facility on site. This stage would then be followed by 80 to 100 years of care and maintenance, before reactor dismantling and final site clearance.
   - ➢ Decommissioning of AGRs would adopt a similar approach. With the design of Sizewell B (PWR), similar principles apply but with potentially differing timescales. (There is no graphite, it is a physically smaller reactor and easier to decommission.)

2. British Nuclear Group's proposed 'Magnox Innovation' approach:
   - ➢ as little as five years to reach care and maintenance and at a cost of £100m or less;
   - ➢ up to 100 years in care and maintenance.

3. The NDA's proposed approach:
   - ➢ defuelling, decommissioning and release of the site for alternative use in 25 years or less.

3.4.2 Decommissioning approach

British Energy Approach

A British Energy review of the early Safestore strategy for their AGR & PWR reactors has recently been undertaken in response to the Regulator's requirements for a review of all operators decommissioning strategies [51]. The overall conclusions of this study were:

- Recent work on worker doses, waste volumes and types, underpins the various AGR decommissioning options, which acted as a driver for the early Safestore.
- Assessments against legislation and Government policy showed that the early Safestore remains consistent and robust, but also flexible.
- Assessments against potential changes in legislation that may be implemented in the future will not significantly impact on early Safestore strategy.
- None of the recently highlighted issues foreclose the current British Energy early Safestore strategy.

BNG Magnox Approach

The Magnox Decommissioning Dialogue [52] was started in 2000, and has been progressing discussions between a wide range of stakeholders with the aim of identifying and exploring implications of decommissioning options. It focused on three scenarios:

- prompt, uninterrupted decommissioning;
- some prompt decommissioning with medium-term deferral of complete decommissioning;
- some prompt decommissioning with long-term deferral of complete decommissioning. In the analysis of the scenarios, some variations were identified, e.g. on-site waste storage, and a rolling programme of decommissioning to completion across all sites.

The resulting recommendations constituted BNG's proposed "Magnox Innovation Approach", with approximately 5 years to reach care and maintenance, at a cost of <£100M, with up to 100 years in care and maintenance. This would include:

- Removal of fuel;
- Retrench all radiological facilities/activities into one area of site;
- Store operational ILW in the reactor building;
- Dispose of LLW on site.

This approach would achieve care and maintenance in about 5 years, and would provide one approach to the interim ILW storage problem.

The NDA Approach

The NDA's long-term objective is to complete the decommissioning and clean up of sites for which it is responsible, and to make them available for other uses. The key issues for the NDA in waste management arising from the decommissioning of power stations are:

- Whether and how to rationalise the interim storage of ILW
- How to dispose of increasing volumes of LLW and to reduce the costs of disposal
- How to manage the future capacity of the National Low Level Waste repository at Drigg, whose capacity is limited, and will not be able to take all LLW from decommissioning and cleanup operations
- The NDA's proposed approach for decommissioning is for defuelling, decommissioning and release of the site within 25 years.

The strategy report suggests the main advantages of the NDA approach to include:

- use of the existing knowledgeable workforce and associated socio-economic benefits for the local area;
- earlier availability of the site for other uses;
- fewer ILW interim stores needed with consequential cost savings;
- visible signs of decommissioning and clean up,
- mitigation of the potential threat of coastal erosion and climate change at a number of sites;

They go on to say that the NDA's proposed approach is similar to that adopted by EDF in France for the decommissioning of their gas-cooled reactors and they note that in Japan, operators propose to decommission their Magnox reactor in 17 years, subject to the availability of a disposal solution.

3.4.3 Current UK decommissioning experience

In the UK, a number of research (non-commercial power station) reactors have been fully decommissioned and the sites delicenced. These include the Risley Research Reactor and the Royal Naval JASON reactor at Greenwich.

There are a number of UK commercial nuclear Magnox reactors which have now completed operations, and are at varying stages of decommissioning. These include

Berkeley, Bradwell, Hinkley Point A, Hunterston A, Trawsfynydd, Chapelcross and Calder Hall. None has completed decommissioning. Berkeley is the most advanced; it ceased operation in 1989. Preparations for care and maintenance started in 1992 following defuelling, and is expected to reach care and maintenance stage in 2009. Details of the decommissioning progress and plans of at each of these power stations can be seen in the Life Cycle Base Lines which British Nuclear Group has prepared for the NDA, and are summarised in the strategy document referred to above. In addition, the future decommissioning plans of the operational Magnox reactors, for example Sizewell A, can also be seen.

Decommissioning of the Windscale AGR is ongoing but projects have been completed to greenfield status for the Capenhurst Uranium enrichment plant and the plutonium fuel fabrication plant at Winfrith.

3.5 Role of spent fuel reprocessing

Spent fuel is fuel that is no longer capable of efficient fission due to the loss of fissile material and the build up of fission products and actinides. After approximately five years in the reactor, the spent fuel consists of about 96% unused uranium, 1% plutonium and about 3% highly active fission products and actinides. Reprocessing of spent fuel was envisaged as a means of extracting the used uranium and the plutonium for recycle in reactor fuel and, in the case of defence programmes, for use of the plutonium in the manufacture of nuclear weapons.

The first reprocessing plant operated at Sellafield from 1952 to 1964. This reprocessed defence fuel from the Windscale Piles and fuel from the first Magnox reactors. There are now two reprocessing plants operating at Sellafield. One treats fuel from Magnox reactors, the other (THORP - Thermal Oxide Reprocessing Plant) treats oxide fuels from UK Advanced Gas-cooled Reactors (AGRs) and water-cooled reactors - principally overseas Pressurised Water Reactors (PWRs) and Boiling Water Reactors (BWRs). Reprocessing of fuel from research reactors and from the Prototype Fast Reactor (PFR) has been carried out in the past at Dounreay. The reprocessing methods and the types of wastes produced were similar to those at Sellafield, albeit on a much smaller scale.

"Wet reprocessing", as practised currently, relies on the initial chemical partitioning of the unwanted fission products and the uranium and plutonium between aqueous and organic phases respectively. In a subsequent stage of chemical partitioning the uranium and plutonium are separated. The aqueous fission product stream ("highly active raffinate") is concentrated by evaporation and stored in cooled, high-integrity stainless steel tanks pending vitrification. Vitrification is the process of converting the highly active liquors into a solid borosilicate glass. This vitrified high-level waste product is placed within stainless steel containers, resulting in a waste form that is safe for long-term storage and that has been shown to be suitable for safe geological disposal in the waste management programmes of a number of countries that have sent fuel for reprocessing.

A large number of operational ILW streams are generated as a result of the reprocessing of spent fuel including fuel cladding materials, sludges, ion exchange resins, plutonium contaminated materials (PCM), and hard trash from plant operations and maintenance.

LLW represents much the largest volume of waste arising from spent fuel reprocessing. Operational LLW consists of a wide range of soft and hard trash from routine operations and maintenance. Waste items include discarded protective clothing, paper towels, general tools, filters, plastic bags and sheeting, pipework, cabling, glassware, redundant equipment, concrete, rubble and soil. Redundant fuel transport flasks and fuel storage pond furniture also contribute to the total of LLW.

The two reprocessing plants at Sellafield are served by a number of facilities, including liquid effluent treatment plants and a variety of plants providing for the management of radioactive wastes. The main plants at Sellafield for liquid effluent treatment are the Site Ion Exchange Effluent Plant (SIXEP) and the Enhanced Actinide Removal Plant (EARP).

In SIXEP, contaminated water from the spent Magnox fuel cooling ponds is filtered to remove particulates and then passed to ion-exchange columns that remove most of the dissolved fission products, such as strontium-90 and caesium-137. The effluent is then monitored and discharged to sea. The discharge of liquid effluents to sea, even after treatment to ensure that they comply with relevant regulatory authorisations, is the subject of continuing criticism both in the UK and internationally, in particular by the Irish and Norwegian Governments, and is one of the reasons put forward in support of calls to end reprocessing.

There is also scientific comment on the selection of borosilicate glass as the solid high-level wasteform. In particular it has been proposed that ceramic wasteforms such as SYNROC (literally synthetic rock) would be more resistant to degradation under long-term geological disposal conditions. However, as noted above, a number of countries have carried out evaluations that show that glass is a suitable wasteform, and the UK regulatory bodies have specifically required the timely conversion of high active liquor to glass to achieve passive safety for the UK's HLW.

A key benefit claimed for the use of SYNROC as a wasteform is its resistance to leaching by groundwater. Since leach rates are not a significant issue in evaluations of the long-term safety of geological disposal of long-lived intermediate-level wastes, and given the difficulties of incorporating the diverse physical and chemical forms of such wastes into a ceramic matrix, SYNROC has not been selected as an appropriate wasteform. Cement-based encapsulating grouts are considered to offer the necessary safety functions and are capable of being tailored to match the different characteristics of different waste streams.

3.6 Partitioning and transmutation

Partitioning and Transmutation (P&T) is a suggested option for reducing the inventory of long-lived wastes. In summary, transmutation is the changing of one nuclide to another as a result of a nuclear reaction: most usually as a result of bombardment with neutrons from a nuclear reactor or, in more recent schemes, from a particle accelerator. In the context of radioactive waste management, the aim is to produce shorter-lived or stable nuclides. As a precursor to transmutation, it would be necessary to chemically separate some of the important radionuclides from other materials: this is known as partitioning.

The MRWS document [15] referred to P&T and pointed out a number of potential difficulties:

- P&T is only a partial solution as there are some long-lived nuclides that will still require an alternative waste management option;
- It may be many years before industrial scale technology is available;
- Adoption of P&T would imply an extension of reprocessing and the construction of transmutation target facilities, and reactors or particle accelerators (which would in turn require decommissioning and give rise to secondary wastes);
- There could be increased worker doses.

It was also noted that in some countries, P&T was seen as only applicable to a new phase of reactor build. It could also deal with redundant military plutonium. The report further point out that the UK has no plans to undertake its own research, but will continue to monitor research being carried out in Japan, US, France and the EU.

P&T would be technically difficult and costly for the current UK inventory of low-level and intermediate-level wastes (LLW and ILW) due to the chemical diversity and the high levels of physical and isotopic dilution at which the target isotopes are present. The application of P&T to vitrified high-level waste (HLW) currently in stock is not considered to be technically feasible on an industrial scale.

For uranium and plutonium, reprocessing technology has been developed and refined specifically to separate these materials from spent fuel. As transmutation of uranium and plutonium requires fission there are, in essence, two options: to use these materials as fuel within a new nuclear programme or to declare them as wastes.

Potentially minor actinides could be partitioned from spent fuel, however this would require the construction of plant to do this.

Although there has been considerable progress in P&T development over the past ten years, P&T remains a long-term venture. The introduction of P&T would require Government decisions, long lead times and large investments in dedicated fast neutron devices, extension of reprocessing facilities, and remotely operated facilities for fuel and target fabrication.

3.7 Costs and funding

3.7.1 Introduction

At the outset of this section it should be noted that simple comparisons of cost between programmes particularly on an international basis are fraught with difficulties and can be misleading. Difficulties with cost comparisons arise from, for example, what is included or not included in the cost, the currency base and year, the volume and types of waste to be disposed of (e.g. inclusion of low and intermediate level wastes along with spent fuel and high level waste), the disposal design concept used, the waste generation scenario assumed, discount rates assumed, inclusion of contingencies, regulatory costs etc.

As a generality, back–end waste management costs comprise the following components:

- waste transport;
- waste treatment and encapsulation;
- decommissioning of nuclear plants;
- interim storage;
- deep repository costs:
    - research and development;
    - site selection, investigation and characterisation (possibly of more than one site);
    - design and construction;
    - operation;
    - decommissioning and closure;
    - contingency;
    - other costs (including organisational).

3.7.2 Long-term waste management costs

The CoRWM cost discussion paper [53] describes the different components of the long-term cost of waste management options and is referenced here. A revised version of this report with greater focus on uncertainties was due to be republished in December 2005. It is acknowledged in the report that there is little information on current waste management costs. The major cost items identified for the options it considered are:

- Planning and licensing: these costs include application costs for facility construction, the cost of stakeholder consultation and public relations, the cost of a public inquiry, R&D costs for concept development and regulatory costs.
- Design and construction: these costs include the cost of the design and

construction of the waste management facility, and of any necessary supporting facilities.

- Operation: these costs include the cost of waste characterisation, packaging and conditioning, operation of the waste management and supporting facilities, facility refurbishment, interim storage and transport costs.
- Decommissioning and completion: these costs include the cost of decommissioning the facility, and of repository closure in the case of the deep disposal options.
- Post-completion: these costs include the cost of monitoring and institutional control.
- Additional costs: these costs include contingency costs, plus the cost of remediation, incentives and insurance, environmental costs and social costs.

Table 5 summarises the findings of the unrevised report for the options mentioned earlier.

A subjective evaluation of the risks associated with the development of each option has been made, using a scale of a high (H), medium (M), or low (L) likelihood of overspend as indicated. Quantifying these risks is highly subjective, but low risks might indicate a contingency of less than 25% and high risks might indicate a contingency of over 100%.

Key uncertainties for the storage options are the construction cost of protected stores, the frequency and costs, of refurbishment, and the savings that might be incurred through development of one large facility versus several smaller facilities. It is difficult to account for the long-term costs of storage beyond say a 300-year period (through for example continuous replacement of stores into the long-term future), and compare these with the short-term costs of direct disposal.

Key uncertainties for the deep disposal options are the scaling of costs in comparison with data for existing or planned facilities to allow for increases in inventory, and the savings in development, construction, and operational costs associated with co-location of repositories for ILW/LLW and HLW/spent fuel. The costs and frequency of refurbishment during care and maintenance are also a significant uncertainty. Nirex has developed cost estimates for the deep disposal options, including incremental costs and cost savings for a co-located facility (see below).

A key uncertainty for the deep borehole disposal option and the mounding option is the cost of developing the technology. Further, neither of these options deals with all of the wastes, and the costs of disposal of the remaining wastes would need to be assessed for comparison purposes.

The costs of near-surface disposal of LLW and short-lived ILW are small in comparison to the costs of deep disposal of all wastes. The cost of including these wastes in a deep repository (£2,000/m^3) may well be less than the costs for their near-surface disposal. The NDA has noted in its strategy document that if plutonium were to be reclassified as a waste, this would potentially add several billions to the overall radioactive waste legacy costs.

The Nirex report N/122 [41] provides cost comparisons for its phased geological repository concept for ILW/LLW, a separate HLW/spent fuel repository and co-located facilities. Note there are certain physical and chemical considerations, and thus safety case implications, that have to be addressed in the design of co-located facilities; this would also mean having a sufficient available host-rock volume to accommodate both types of facility.

See the following tables for further details:

- Table 6: Stand-alone ILW / LLW repository programme and costs
- Table 7: Stand-alone HLW / Spent fuel repository programme and cost estimates

- Table 8: Co-location of ILW/LLW with HLW/spent fuel repository programme and cost estimates

3.7.3 Decommissioning costs and funding

The NDA strategy document presents estimated life-cycle costs for each of its sites and are summarised in the following table. These are based on Life Cycle Baseline reports produced for each site and are shown in Table 9.

The total cost shown is £55,852m but against this should be offset an income of £11,380m from ongoing operations including electricity sales (£1,374m), waste disposal services at Drigg (£144m), reprocessing contracts at Sellafield (£7,481m) and fuel services at Springfields (£2,381m) plus a further £1,202m of other income. This provides a net cost total of £43,270m.

The NDA also says that this figure could be offset by savings from new approaches and innovation to decommissioning and clean up through experience in the US nuclear clean up industry. The NDA also underline the importance of using competition as a key means of achieving better value for money for taxpayers. However, they also caution that the total could be considerably higher due to changes in the cost of dealing with the higher hazard legacy facilities especially at Sellafield and any reclassification of certain nuclear materials as waste.

In arriving at the costs the NDA strategy document indicates that each of the sites has an end-state in mind (i.e. mainly "green field" or "brown field") for planning and costing purposes. However, it adds that the green field assumptions do not take account of the flexible approach allowed in Government decommissioning policy (see section 2.3) which would not necessarily mean such an end-state. The NDA stress that the views of local stakeholders will be sought to reach a consensus on the way forward.

Funding arrangements for the NDA are set out in the 2004 Energy Act. The NDA is funded by the Government through the Nuclear Decommissioning Fund as provided for under the Act. The funds are a combination of general Government spending and revenue from commercial activities on the NDA sites. Nirex, while separate from and independent of the NDA, obtains the majority of its funding through the NDA (the remainder being form the Ministry of Defence).

Under the 2004 Energy Act, the NDA, on behalf of the DTI, oversees British Energy's (BE) planning for decommissioning of its plants. This includes approving BE's decommissioning strategies and approving payments to BE by the Nuclear Liabilities Fund (NLF, set up as part of its restructuring arrangements). Unless the NDA is otherwise directed, it assumes no direct responsibility for BE's decommissioning work, but will ensure that BE undertakes these activities in a cost-effective manner that is consistent with the NDA draft strategy. Under BE's restructuring plan it pays into the Nuclear Liabilities Fund (NLF) to cover its decommissioning costs; the fund is underwritten by Government.

4 RADIOACTIVE WASTE MANAGEMENT IN OTHER COUNTRIES

4.1 General

There are some 39 countries with a civil nuclear power programme and some others with only research reactors or other significant sources of radioactive waste (excluding mill tailings etc.). It is often stated that there is international consensus on deep geological disposal as the preferred option for long-term radioactive waste management. A 2004 survey of those countries [[54]] indicated the Governments of 18 countries (now 19) have taken a final decision on policy and have opted for deep geological disposal. A further 11 countries (now 10) had expressed a preference for deep geological disposal.

Many countries have already implemented disposal for their short-lived wastes (often defined as those containing radionuclides with a half-life of less than ~30 years) and there are many examples of such repositories around the world. These wastes only need to be isolated from man's environment for about 300 years (ten half-lives) until the radioactivity levels are such that the waste is radiologically safe. Some of these repositories can take limited amounts of long-lived low-level wastes subject to safety case considerations.

It should be noted that there are no internationally agreed definitions of waste categories, effectively each country has its own classification system relating to its waste types. Below is given a brief overview of the repository programmes in a number of countries.

4.2 Low and intermediate level waste disposal

Near-surface repositories for such wastes exist in: France at Centre de la Manche, Centre de l'Aube and Morvilliers for VLLW; Japan at Rokkasho-Mura; Spain at El Cabril, the US for example at South Carolina, Utah, Washington State, Nevada; and many other countries. Note that Drigg in the UK only takes low-level waste.

Other concepts include disposal in former mines (including Germany, Czech Republic). The one Swedish and two Finnish operating repositories for short-lived wastes are several tens of metres deep.

In many Former Soviet Union countries and Russia itself, there are examples of operating near-surface repositories which were built to take the wastes from Soviet designed research reactors. Some have subsequently been extended to take institutional wastes, such as those from medical uses, research and industry; these are known as "RADON" type facilities.

In Germany, the Morsleben repository for short-lived waste is at a depth of 524m in a former salt mine; it ceased operations in 1998 and is now undergoing closure. The Swiss had a concept for horizontal access into the side of a mountain for this type of waste (but the site selection process failed) but such an idea is being implemented at Himdalen in Norway and Bátaapáti in Hungary.

4.3 Long-lived waste disposal

If long-lived wastes such as HLW, spent nuclear fuel, transuranic (TRU), long-lived intermediate level waste, and long-lived low-level wastes are to be disposed of they need to be buried at a depth of several hundred metres. The half-lives of some of the components of these wastes are many orders of magnitude greater than for short-lived wastes. It is therefore important to isolate these wastes from man's environment for a very long time. Burying at depth will ensure that events such as glaciation do not expose the waste, there is a limited risk of accidental intrusion by a future society, and that the return time and dilution of contaminated groundwater is such that drinking water levels are unacceptably safe.

Belgium considers two scenarios, one with full reprocessing of spent fuel and one with no further reprocessing with the direct disposal of the remaining spent fuel. In the first scenario some 5,000te of vitrified HLW would be disposed of at a depth of 250 metres in a clay geology. It has not yet started a siting programme for the deep repository but has an underground research laboratory (URL) at Mol.

The Canadian concept considers the direct disposal of some 70,000te of spent fuel at a nominal depth of 1,000m in a crystalline rock. It has just finished a consultation programme on the way forward for managing its nuclear fuel waste and so has yet to start a repository siting programme if disposal is the accepted way forward. In Canada, the Nuclear Waste Management Organisation has made a recommendation to Government in November 2005 for an "adaptive phased management approach" for the management of spent nuclear fuel. This is not too dissimilar to the Nirex Phased Geological Repository Concept.

In Finland, Posiva Oy, the waste management organisation, has now selected a site for a deep repository for spent fuel at a site in Eurajoki, nearby to the Olkiluoto nuclear power station. Should investigations be successful it anticipates applying for a construction permit around 2012 with operations beginning in 2020 in line with Government requests. The Finns plan to dispose of their ~3,000te of spent fuel at a depth of about 500m in crystalline rock. Their programme is perhaps the most mature - with construction of an underground research facility (ONKALO) taking place. As at December 2005, the drift access had been constructed to a depth of approximately 100m (of an estimated total depth around 500m) and a length of nearly 1 kilometre.

A limited amount of long-lived waste was disposed of in the Asse salt mine in Germany as part of its research programme. Also in Germany, the Konrad repository for non-heat generating wastes has received a licence to operate but this has not been implemented to date because of court action. However, this is hoped to be resolved in 2006.
Spain has yet to decide on implementing a disposal programme.

Sweden's concept is based on the disposal of nearly 10,000te of spent fuel at a depth of 500m in crystalline rock. The waste management organisation SKB is investigating sites nearby to Forsmark and Oskarshamn nuclear power stations; it intends to select a single site by 2008 and have construction of a repository completed and ready for first waste emplacement by 2015. They too have a URL at Äspö, near Oskarshamn which also hosts a nuclear power station, the spent fuel encapsulation laboratory and the CLAB interim spent fuel store.

The Swiss concept considers the disposal of a mixture of spent fuel and vitrified HLW – equivalent to about 3000te of spent fuel at a depth of about 650m in a clay geology. Site investigations are taking place in the north of the country and the Swiss are also considering the co-location of low level waste in the facility, following the earlier failure of a separate siting programme. They too have URL at Mont Terri in the north and at Grimsel in the south.

In the US, the Department of Energy has selected the Yucca Mountain site in Nevada. The concept here considers the disposal of some 110,000te of spent fuel and ~13,000 te of vitrified HLW at a depth of 450m in the volcanic tuff. It is the only "dry" repository concept in the world. The US has a separate repository near Carlsbad, New Mexico, the Waste Isolation Pilot Plant (WIPP). It is currently the only operating deep geological repository for long-lived waste in the world. This facility takes defence related transuranic wastes (similar to long-lived ILW) and has been in operation since March 1999.

4.4 International decommissioning experience

The Nuclear Energy Agency of the Organisation for Economic Co-operation and development (NEA/OECD) is just one of several international organisations with an interest in decommissioning nuclear plants. It regularly holds workshops and seminars and has published several documents on the subject. In September 2004 the NEA published a brochure [[55]] which gave examples of decommissioning projects around the world, including (in addition to some UK examples mentioned earlier):

- Uranium conversion plant in Korea which is ongoing until 2007;
- Fuel fabrication plants at Hanau in Germany;
- Power reactor decommissioning:
  - Japanese 10 MW(e) demonstration reactor (1996);
  - 100 MW(e) heavy water reactor, Niederaichbach, Germany (1995);
  - 300 MW(e) Fort St Vrain gas-cooled reactor, USA (1992);
  - 900 MW(e) Maine Yankee PWR, USA (2005);
  - 670 MW(e) PWR, Würgassen, Germany;
  - Trojan 1180 MW(e) PWR, USA;
  - Connecticut Yankee 582 MW(e) PWR
- Eurochemic reprocessing plant Belgium which is ongoing until 2008.

The NEA also held a workshop in September 2004 [[56]] from which the main messages to emerge were, in summary:

- **Decommissioning is a mature industrial process** and many projects have been safely completed with support of local communities. Technical and scientific issues are well understood and practical experience and associated lessons are being documented to guide future activities.
- **Individual countries need to further develop integrated decommissioning and waste management strategies** to ensure that long-term solutions will be available for all wastes generated from decommissioning.
- **Realistic and streamlined regulatory programmes are being developed** with feedback from industry experience and are placing more responsibility and accountability on licensees.
- **Accurate decommissioning waste cost calculation methods is needed.** Further work and experience exchange on cost comparisons between different strategies (for example clearance and recycling/reuse of materials versus direct surface disposal) would be valuable.
- **International clearance criteria have been established**, with individual countries free to adopt them.
- **Financial mechanisms for decommissioning funding are evolving in the NEA member states** to meet regulatory and project needs. Continuing challenges are uncertainties in cost estimates and the implementation of measures to assure that funds will be available when required.
- **Creative research on decommissioning is being carried out.** Human factors and organisational issues are studied. Practical solutions are being implemented such as the use of management transition programmes. Some increased efficiency and effectiveness is needed by way of R&D on improving technology and developing innovative techniques, subject to justification of its cost and value.
- **Continuing emphasis on education in critical nuclear skills is needed** to ensure availability of the necessary expertise for both near-term decommissioning needs and long-term energy needs.
- **Public acceptance is still a major challenge**. Without public acceptance,

decommissioning may be prolonged and difficult to implement.

4.5 Financing radioactive waste management in other countries

This section of the report describes the funding arrangements for radioactive waste management and decommissioning in a number of European countries, and the US. The prime source of the information has been derived from the national waste management organisations' published material and from other studies, such as and EU study published in 1999 [57]. As a generality, financing schemes follow the "polluter pays" principle.

In mid 2002, the European Commission, through DG Energy and Transport (DGTREN) attempted to introduce a "nuclear package" of proposed Directives and regulations aimed at harmonising measures for nuclear safety and radioactive waste management in an enlarged EU. Part of the package was a proposed Directive on Funding Nuclear Liabilities at the end of Facility Life. The idea was that all nuclear facilities should have segregated finds to cover the costs of decommissioning, so that this aspect of electricity pricing was transparent. The move was motivated by the opening up of the energy markets in order to avoid obstacles to fair competition. This part of the package has since been removed, however, it is clear that there remains an interest in the Commission and European Parliament to see financing measures in place.

4.5.1 Belgium

Belgium operates a "reservation of capacity" financing scheme which protects against financial uncertainties in the reference disposal programme. There are two sources of funding. For ongoing waste production, the waste producers pay fees to the national waste management organisation (ONDRAF/NIRAS) to cover waste treatment (if appropriate), interim storage. In addition, fees are paid into the "Long-Term Fund", administered by ONDRAF/NIRAS, to cover all final disposal liabilities. Historic liabilities (pre-1989), nuclear plant decommissioning and site restoration are funded by special agreements between the Belgian State and the electricity sector.

4.5.2 France

The national waste management organisation of France, ANDRA , runs L/ILW and VLLW disposal facilities for which a charge per package is levied. ANDRA's deep site programme is pre-financed under contracts based on customers volume forecasts for the deep repository. EdF's decommissioning, waste disposal (to ANDRA) and reprocessing activities are funded through provisions for liabilities out of electricity income. COGEMA includes a decommissioning fee in its customer reprocessing contracts.

4.5.3 Finland

The two nuclear operators, Fortum and TVO, pay separately into the segregated Nuclear Waste Management Fund. The contribution is about 10% of the cost of nuclear electricity and is determined by the Government which manages the fund through a Board of Governors. The fund's assets must match the liabilities which includes conditioning storage, and disposal of spent fuel and decommissioning waste. Fortum and TVO have the right to borrow up to 75% of their own contribution backed by guarantees. The State may borrow other 25%. If the rights are not exercised, the fund lends on the open market. (See also section 4.7.3.)

4.5.4 Germany

Waste producers must bear all costs for radioactive waste management and disposal as prescribed by law. Nuclear utilities build up (tax-exempt) reserves to pay for future management and disposal. The pre-operational financing for Konrad and Gorleben repositories (non-operational at this time) were paid for by the nuclear utilities, nuclear research centre and small producers. For the operational repository at

Morseleben, which was commissioned by the former GDR Government and has now closed, waste producers paid a volume based fee for disposal; however, closure operations are being financed by the Federal Government.

4.5.5 Netherlands

The national waste management organisation COVRA charges fees to waste producers for all direct costs for transport, conditioning and storage and eventually disposal (even though a decision on that has been deferred for 100 years). The future disposal fees are placed in a capital growth fund.

4.5.6 Spain

(Note, this is subject to imminent change.) Low and intermediate-level waste disposal fees at El Cabril are dependent on waste type and volume. For spent fuel management and disposal, and decommissioning the financing is based on a levy on electricity prices. This is paid into a segregated fund (managed by ENRESA) and applied across the whole electricity sector. The fee is determined by a complex method based *inter alia* on nuclear power station output. The fund also finances historical (pre-fund) liabilities.

4.5.7 Sweden

In Sweden a fee system has been set up based on nuclear plant output which covers cost of spent fuel management and decommissioning. The fee is calculated based on the operational life of the reactors (40 years is assumed) by national waste management organisation SKB and submitted to SKI (the Swedish Nuclear Power Inspectorate) which in turn seeks approval from the government for the fees to be applied.

4.5.8 Switzerland

Nuclear utilities cover present waste management costs as they arise and future costs by means of reserves which are levied annually. The amount is calculated such that sufficient funds will be gathered during the lifetime of the plant to cover decommissioning, management and disposal of waste. Provision was made under the law for the setting up of a decommissioning fund which has its own legal identity and is managed under the supervision of a Commission appointed by the Federal Council. The NPP owners pay into the fund an amount determined by the Commission.

4.5.9 USA

Under the Nuclear Waste Policy Act (NWPA) nuclear utilities pay 0.1cent per kWh of nuclear electricity into the Nuclear Waste Fund. The fund pays for a component of the waste management research programme at Yucca Mountain, the other component coming from Defense Department funding. The fund is not a segregated fund and US Department of Energy has to ask Senate / Congress each year for its budget appropriation. Funding of historic enrichment plants liabilities comes from a separate Federal fund. Decommissioning of NPPs is the responsibility of the owners.

The Atomic Energy Act requires the owner to decommission at the end of life, and take financial responsibility for this (apart from high-level waste). Four types of funds are acceptable to the Nuclear Regulatory Commission: external fund that builds up over facility lifetime; prepayment account kept separate from other assets and outside its control; surety bond, letter of credit or insurance which guarantees payment if the utility defaults; and corporate self-guarantees based on certain financial criteria.

4.5.10 Other Countries

In Bulgaria, the nuclear plant operators pay 3% of the electricity selling price into a waste management fund and 8% into a separate decommissioning fund, both created in 1999. In the Czech Republic, the operators pay a levy based on installed capacity into nuclear account. Decommissioning costs are covered by financial reserves. Hungary has a Central

Nuclear Financial Fund operated by the Atomic Energy Authority into which the nuclear operators pay a levy of about 4% of the consumer price.

In Lithuania an electricity levy for Ignalina NPP is paid into its decommissioning fund; currently the activities of its waste management organisation are paid for through the State budget. Slovakia has a State Fund for decommissioning, spent fuel and radioactive waste management into which Slovak Electric pays 10% of the selling price of nuclear electricity. In Slovenia there is an independent fund for waste management and decommissioning established which includes local nuclear community representatives; the situation here is complicated by the fact that its single nuclear power station is jointly owned with Croatia and there is ongoing bilateral discussion regarding financing issues.

4.6 Case Study –Vandellós I NPP decommissioning

4.6.1 Technical details

Vandellós-1 was a 500MW(e) gas-cooled, graphite-moderated reactor (see Figure 4: Decommissioning of Vandellós I nuclear power plant, Spain (Courtesy ENRESA)), which used metallic natural uranium fuel, clad in a Magnox alloy within a graphite sleeve. It is located about 75 miles south-west of Barcelona on the coast. The site also contains Vandellós 2 PWR and a new gas plant is under construction.

Unlike the UK Magnox stations, it was a single unit plant. The pre-stressed concrete reactor pressure vessel contained the nuclear steam supply system, the core and steam generators. The unit was constructed between 1967 and 1972, and operated from 1972 to 1989, when a serious fire in the turbine hall brought its operation to a close. Whilst there were no radiological consequences of the fire and only damage to conventional plant, the expense of upgrading to new regulatory requirements led to the decision of permanent shutdown.

Vandellós I is the first nuclear plant to be decommissioned in Spain. Information for this part of the report is taken from a recent article in Nuclear Engineering International [[58]], the decommissioning report for the plant [[59]], from direct contact with ENRESA personnel and from visits to the plant.

Stage I decommissioning (as defined by the IAEA) comprising initial defuelling and graphite waste conditioning operations were the responsibility of the plant owner, Hifrensa. The Magnox fuel elements were shipped to France for reprocessing with conditioned graphite sleeves remaining on site. In addition, certain conventional disassembly operations were carried out, such as the CO_2 tanks and the main turbine-alternator sets. This stage was completed in February 1998.

Stage II decommissioning is the responsibility of ENRESA, the Spanish public company responsible for radioactive waste management and decommissioning, which took over operations at the site at the end of Stage I. This stage of decommissioning initially consisted of dismantling and demolishing most of the buildings on the site external to the reactor box, sealing the reactor pressure vessel and reducing the height of the reactor building by some 30m (see Figure 4). The only radiologically controlled zone is the reactor basement which houses the conditioned graphite interim-store.

LLW and short-lived ILW was disposed of at Spain's El Cabril near surface repository and large amounts of material have been recycled off-site or for non-active material used as on-site infill. The radioactive components that remain on site are mainly the graphite core and activated components within the primary containment, and containerised crushed graphite.

A major feature of this phase was the segregation of active and non-active waste materials to determine whether they could be recycled, conventionally scrapped, decontaminated or needed to be treated as

radioactive waste. ENRESA set up a sophisticated control system that ensured no material leaving the site for conventional destinations exceeded the regulatory levels of activity.
Between 1998 and 2003 some 15,900te of mainly metallic material was generated and recycled; minor amounts of conventional hazardous waste was sent to authorised disposal tips. Of this about 8,000te originated in the active zones and was declassified and cleared.1,961te of rubble from the active zones of the plant were cleared for land restoration along with 77,000te of concrete from the demolition of buildings.

1,763te of low and intermediate level radioactive waste was generated and disposed of at El Cabril through 188 transport operations. As noted above, conditioned graphite and some other fuel sleeving components remain stored on site.

The initial phase of Stage II was completed in June 2003 and the reactor safe enclosure is now in a latency period (*c.f.* care and maintenance) of 25-30 years before Stage III decommissioning commences to take down the reactor building and restore the site. This latency period will allow the radioactivity in the internal structures to decay naturally to about 5% of current levels.

The concrete safe enclosure contains only the reactor pressure vessel with 5m thick walls and top and bottom slabs 6-7m thick. The activity content of the vessel is about 4,000TBq of mainly Co-60 and the residual heat is between 4-5kW. The vessel has 1700 penetrations which were cut, seal welded, inspected and the covers insulated with polyurethane foam to avoid condensation. The leak-tightness of the vessel is regularly checked with satisfactory results. To the end of 2003, Stage II has cost €94M, (€4M over budget) and took 63 months compared to the 60 months originally planned.

4.6.2 Stakeholder engagement

In planning and undertaking the decommissioning, ENRESA has to address the expectations and concerns of a number of stakeholders, including the regulators, local authorities, the existing workforce, media and the general public.

As well as developing a detailed engineering project plan and waste management strategy, ENRESA has established policies for training and motivating former plant employees, employment, safety and transparent communication.

ENRESA has promoted links with local political parties and public institutions. For example, local press briefings and seminars are organised to discuss different aspects of the decommissioning. Relations with the public include organising visits and provision of information to allow them to gain an insight to the activities. The site hosts a visitors centre and the site tours cover the whole site including the reactor basement (including viewing windows looking directly into the waste store), the pile cap and roof. There are between 2000 and 5000 visitors each year. By the end of 2003 over 24,000 people had visited the site, almost 80% being from educational institutions. The other 20% being official national and international organisations, media, industry and other institutions.

Promotion of local employment was also seen as a key feature of the decommissioning work. Some 63 different companies have worked on the project with a peak of 30 companies and 420 workers on site at once, with 65% of the workers involved coming from the local municipality. 1500 training courses have been run and there have been no serious accidents.

4.7 Case study: Finland

4.7.1 Introduction

The Finnish case study considers the waste management strategy being implemented and the relationship with the decision to build a new nuclear reactor at Olkiluoto. Finland is often cited as an example of where positive steps have been taken in both implementing a waste management policy, and on taking a decision for new nuclear power stations.

Under the 1987 Nuclear Energy Act, the first step towards a new nuclear facility, final repository or power station, is the so-called Decision in Principle (DiP). At this step the Government has to consider whether “the construction project is in line with the overall good of society”. In particular, the Government pays attention to the need for the facility, the suitability of the proposed site and its environmental impact.

Under the requirements, the Radiation and Nuclear Safety Authority (STUK) has to make a preliminary safety appraisal of the DiP application and the proposed host municipality must state its acceptance or rejection for siting the facility. The decision has then to be endorsed by the Parliament. The application for the DiP also includes submission of an Environmental Impact Assessment (EIA) report for the planned facility.

4.7.2 Overview nuclear power in Finland

Finland has four nuclear reactors providing 27% of its electricity; two Soviet designed VVERs at Loviisa owned by Fortum, and two Swedish BWRs at Olkiluoto owned by TVO. A parliamentary vote in May 2002 supported the building of a fifth reactor, a 1600MW(e) EPR design, a decision made through the DiP process. The plant is now under construction for 2009 start-up. This was the first decision for a new nuclear power station in western Europe in over a decade. The site of the new unit was agreed in October 2003 and is at TVO's Olkiluoto site.

The country's 1997 energy policy stressed availability, security, diversity, price, and the need to meet international environmental commitments. For electricity, Finland is part of the deregulated Nordic system, which faces shortages, especially in any dry years, which curtail hydroelectric generation. With growing demand and the need to ensure reliable economic supply over the long term, various studies were carried out which showed that nuclear power was the cheapest option for Finland.

TVO is a public-private partnership company, 43% Government-owned, 57% private, with the owners taking their shares of electricity at cost, any unwanted portion being sold into the Nordic market. This means that output is effectively contracted to each owner over the life of the plant. The private owners are mostly heavy industry with a high demand for base-load power, and hence low costs are critical for them.

The 1987 Nuclear Energy Act allowed both final disposal within Finland and the export of Loviisa spent fuel to the Soviet Union. Finland affirmed its long-term management option as deep geological disposal within the country in 1994, when an amendment to the Act meant that all spent fuel should be managed within the country. As a result, in 1996 the export of spent fuel from Loviisa to the Mayak reprocessing complex in Russia, under a complete fuel cycle service arrangement connected with the supply of the reactors, ceased.

At Olkiluoto, surface pool storage for spent fuel has been in operation since 1987. The facility has 1270te capacity and is designed to hold spent fuel for about 50 years, pending disposal. At Loviisa, expanded interim storage pools was required by the expiry of the Russian arrangement, were commissioned in 2000.

4.7.3 Waste management funding and costs

Responsibility, including costs, for nuclear wastes remains with the power companies until its final disposal. The State Nuclear Waste Management Fund is an external fund controlled by the Ministry of Trade and Industry (MTI), and was established under the 1987 Act. The fund is required to cover all the costs of all nuclear waste management including operational waste disposal at each site, decommissioning waste disposal and spent fuel disposal. Contributions to the fund are collected through the price of nuclear electricity.

As of mid 2005, ~€1.4Bn had been accumulated in the fund . The charges are set annually by the Government. Overall costs of radioactive waste management, including decommissioning, are estimated at about 10% of total power production cost.

4.7.4 Waste management implementation

Finland does not reprocess its spent fuel, and so does not generate significant quantities of long-lived ILW. Spent nuclear fuel is considered a waste and is planned for disposal. The main waste streams which require management are spent nuclear fuel, LLW, and short-lived ILW. An underground repository at Olkiluoto for low and intermediate-level operational wastes has been in operation since 1992. Construction of this cavern took three years and cost ~£10M. A similar facility at Loviisa has been operational since 1998. Both will be expanded to take eventual decommissioning wastes from each station.

Process

Finland's nuclear waste management program was initiated in 1983 soon after the four reactors started commercial operation, when the Government set guidelines and a schedule for long-term nuclear waste management. The policy included legislation to ensure public participation, and a local right of veto on the siting process. Work on siting has proceeded over twenty years. In 1983 TVO drew up a list of 101 sites which was published and undertook a consultation process with the affected communities. This resulted in the identification in 1985 by TVO of 5 potential volunteer sites at which more detailed investigations were carried out between 1986 and 1992. In 1992, TVO announced that further investigations would only be carried out at three sites, including Eurajoki (near to the Olkiluoto nuclear site). However, at the request of the local community in Loviisa, it was added to the list.

Posiva Oy was set up in 1995 as the organisation responsible for implementing spent fuel disposal and it took over the siting programme from TVO. It is jointly owned by the nuclear plant owners. In May 1999, Posiva submitted an Environmental Impact Assessment report to MTI and a DiP application for Eurajoki to the Government, although the EIA report itself had to consider the alternative three candidate sites.

After hearings in November 1999, the Ministry gave its statement, which completed the EIA process. During the hearing period 15 authorities and public bodies, 5 civic organisations and communities and 23 municipalities submitted their statements on the EIA report to the MTI. In addition, some 15 private persons sent their opinions.

The opinions expressed by the authorities and municipalities were mainly positive and the EIA report was regarded as wide and thorough, although one concern was the potential deterioration of the image of the municipality. The anticipated health impact by spent fuel transport was also of concern. The opinions of private individuals and civic organisations on the EIA, as well as on the whole disposal project, were in general critical and opposing. Their viewpoints were, however, mainly focused on issues outside the scope of the EIA.

The MTI concluded in its statement that the EIA was sufficiently comprehensive and detailed and fulfilled the requirements set by the EIA legislation. The Ministry indicated that the construction licence application for the facility (scheduled to be submitted after 10 years at the earliest) should include an updated EIA report.

STUK engaged an international review team, to support its preliminary safety appraisal of the DiP application. The team summarised their findings in a consensus report to STUK in October 1999. In addition, STUK requested statements from several Finnish research institutes which have participated in the publicly funded waste management research programme. STUK submitted a preliminary safety appraisal of Eurajoki to MTI in January 2000. In this appraisal STUK concluded that the prerequisites for a DiP from the standpoint of nuclear and radiation safety were met.

In January 2000, the Eurajoki council gave its approval to the DiP application (20 votes for, 7 against) and ratification by Parliament by a 159 to 3 vote was given in May 2001.

Progress

Posiva has adopted SKB's spent fuel disposal concept. An underground rock characterisation facility - ONKALO – began construction at the site in the summer of 2004 and will be completed by 2010. It will have characterisation levels at 420m and 520m. This will eventually be excavated at the 420m level to construct the repository, subject to satisfactory investigations and regulatory approval.

A construction licence for the repository and the associated fuel encapsulation plant will be sought about 2012, with a view to operation from 2018. Encapsulation will involve putting twelve fuel assemblies into a boron steel canister and enclosing this in a copper capsule – i.e. the SKB concept. Each capsule will be placed in its own hole in the repository and backfilled with bentonite clay. Access to the tunnels will be maintained and the spent fuel will be recoverable.
The cost estimate for disposing of 2600tU of spent fuel from the four existing reactors during 40 years of operation is about ~£550M, including construction costs of ~£150M, encapsulation and operating costs ~£360M. With the fifth reactor, some 6500te of spent fuel will require disposal. By the end of 2004, 1380tU had been accumulated at both nuclear power station sites.

Operational and decommissioning waste

As noted, ongoing arisings of LLW and short-lived ILW are disposed of at each of the sites and decommissioning waste will also be accommodated there.

Although reactor decommissioning is the responsibility of the two power companies separately, they do undertake joint research. Plans are updated every five years. Further, Posiva reviews the plans for both decommissioning and operational wastes, and publishes annual reports on its findings.

4.7.5 Discussion

There are several points to note in reflecting on the Finnish experience, with regards to the decision on new reactor build, and associated waste management.

These include:

Long term planning: the establishment of a clear long-term policy of waste management, and also the time necessary to implement it, should be noted. The waste management programme was established in 1983, and a policy decision on deep geological disposal was affirmed in 1994. A decision on a final site was taken in 2001, and the facility is expected to be in operation in 2020.

Public Involvement:

- The involvement of the local communities has been enshrined in the decision-making process, including provision of a veto at key decision points. This has led to robust decision-making.

Legislation:

- The waste management programme and public approval of final disposal have been supported by appropriate legislation, which has been adapted to the values of society and prevailing attitudes.

Waste management strategy:

- The wastes requiring management in Finland are not as complex as in the UK, arising mainly from nuclear power generation. It has been possible to identify clear and appropriate waste management strategies, based on sound science that have also secured public acceptance.

New build:

- Following an open debate, including involvement of the waste management organisation, Finland has commissioned a fifth nuclear reactor and is considering a further one. The process for the fifth reactor was similar in law to the decision process for the repository and permission for its construction given in the knowledge that a disposal route was available for spent fuel and other waste arisings.

5 NEW BUILD

5.1 Introduction

The government announced in its 2003 Energy White Paper, that the nuclear energy option is to be kept open and stated that: 'at some point in the future new nuclear build might be necessary if we are to meet our carbon targets' [60]. The White Paper also pointed out that "... there are also important issues of nuclear waste to be resolved. These issues include our legacy waste and continued waste arising from other sources."

Before building any new nuclear power stations there would have to be the "fullest public consultation" which the Prime Minister has said will commence in 2006, with the aim of making a decision on nuclear power during this parliament [61]. It is assumed such a consultation will need to address the waste implications of a new nuclear build programme, as foreshadowed in the White Paper.

With regards to waste management, any wastes arising from a new build programme would need to follow regulatory guidance with regards to conditioning, packaging, and ensuring that wastes were assessed for future disposability. Ideally, waste management and decommissioning issues should be addressed at the beginning of any new build discussions. The involvement of the waste management organisation charged with implementing any policy on long-term waste management in decisions regarding the technical design of new reactors would bring benefits. For example, if the new reactor design were to give rise to new or novel materials which might have an impact on for example, decommissioning practice or repository safety, early discussions could identify any appropriate design impacts early on and these be minimised.

The current nuclear programme is expected to come to an end by 2035 with the scheduled closure of the Sizewell B PWR. It has not yet been decided which reactor type would be adopted as part of any new build programme; however, certain types of reactors have been suggested as potentially viable for the UK e.g. the Westinghouse AP1000 PWR, the Advanced CANDU reactor, the Pebble Bed Modular Reactor (PBMR) and the European Pressurised Water Reactor (EPR).

All these technologies are expected to be ready for implementation within the next 20 years. The UK has also been involved in a collaborative international research and development project on promising new nuclear energy systems that would meet future energy challenges [62], this is known as the Generation IV Forum. Six reactor types have been recommended by this forum for further research on the basis of the ability to meet certain goals which could potentially be implemented within the next 50 years.

5.2 The MRWS programme and new-build

The MRWS document was relatively silent on the potential outcome of the process and its effect on a decision for new build. It stressed that even if no new nuclear plants were built there is still the legacy of wastes to be dealt with, but it did acknowledge that in addition to the economics, the future role of nuclear will depend on securing public confidence in relation to issues such as safety and the environment, indicating for example that waste management would need to be addressed.

CoRWM has not explicitly sought views on new build in its consultations. However, many respondents have raised the issue. The relationship of CoRWM's recommendations and new build is important to many, with some arguing that a decision is needed to enable new build, and some arguing that the difficulty of long-term radioactive waste management means it would be irresponsible to create further wastes. Further discussion on these aspects can be found through the CoRWM website. It remains to be seen how the MRWS process may deal with the new build issues.

5.3 Inventory implications

5.3.1 Volume implications

With regard to future nuclear power generation, the House of Lords Science and Technology Select Committee report [] concluded that the volumes of long-lived waste from the construction of a “small number” of new reactors would have little effect on waste volumes and, in this sense, the Committee did not strongly link this to the choice of long-term waste management option.

In CoRWM’s inventory study [], the waste volume implications for a 10GW(e) installed capacity for different reactor types were presented. These assumed no reprocessing and that spent fuel would be packaged in standard 1.1m diameter canisters used in SKB’s KBS-3 Swedish disposal concept. See Table 10: Waste volume arisings for 10GW(e) installed capacity.

The Nirex Reference Repository Concept for UK high-level waste and spent fuel is based on the KBS-3V concept, including canister design. Canister dimensions have been modified (but not optimised) to accommodate UK HLW/SF (i.e. varying lengths and 0.9m diameter). The Nirex estimates packaged volumes for both the baseline (AGR and PWR) are therefore lower than those estimated by CoRWM – see Table 11.

5.3.2 Activity implications

Waste volume is not the only criteria which may impact on the design or capacity of a waste management or disposal facility. Radionuclide inventories, and chemical and physical characteristics could all have an impact on how an option is implemented.

CoRWM estimate that, for the scenario of life extensions to existing AGR and PWR stations and a programme of 10 new reactors, the amount of radioactivity could be up to a factor of 5 greater than the baseline [46]. However, estimating the percentage increase in radioactivity from 10 AP1000 reactors is complex as the increase is dependent on a number of assumptions. For example higher burn up for fuels in new reactors would lead to higher specific activities. Moreover the reference time chosen for the comparison is dependant on the presence of short-lived radionuclides, which dominate when fuel is taken out of the reactor.

Table 12 has been prepared by Nirex and shows the percentage increase in radioactivity for radioactive wastes and spent fuel from 10 new AP1000s for decay times of 10, 50 and 100 years after removal from the reactor. These represent the years 2090, 2130 and 2180 if it is assumed that the new build operation is between 2040 and 2080. Note that LLW has been excluded from the table as this represents only a small fraction of the total activity.

Thus, the increase in total activity could be as high as a factor of nine, 10 years after final fuel removal which decreases to a factor of 0.9 of current total activity 100 years after final fuel removal.

5.4 Spent fuel and operational waste management implications

It is assumed that the radiological as well as physical and chemical characteristics of the LLW, ILW and spent fuel from AP1000 or EPR reactors would not differ significantly from those produced by the existing PWR at Sizewell. As the AP1000 reactor is based on a passive design, fewer components are required which means less waste during the operation and the decommissioning of the plant. Also the absence of an active emergency core cooling system and other simplifications are also expected to have a significant impact on the size of the auxiliary buildings. This could also lead to a reduction in the amount of waste produced during the decommissioning of the plant. The AP1000, EPR and ABWR would not pose any significant new waste packaging challenges (assuming regulatory stability).

The PBMR contains much graphite as both moderator and fuel and thus will make up a large proportion of the waste. This graphite will be contaminated despite the favourable fission product retention capabilities of the fuel and will create a disposal challenge mainly due to its volume, porosity, leachability, carbon-14 content and flammability. Most of this graphite (non-fuel) could potentially be purified and reused for nuclear purposes. The fuel design allows for direct disposal in casks without any further fuel processing and the graphite (in the form of carbon spheres) is a stable long-term disposal waste form and could be packaged using existing technologies. It is thought that special overpack materials will not be needed and this may consequently have an effect on the volume of the waste.

As can be seen from Table 10, the unpackaged volume of PBMR spent fuel is significantly larger than the packaged volume of spent fuel from the other designs; moreover, the packaged volume is expected to be even greater than this. However, the fuel has a relatively low decay heat because of the presence of graphite which may mean that the packages can be emplaced together more closely in a repository than other types of spent fuel.

In the case of Advanced CANDU's, these use enriched uranium dioxide fuel as do the current AGRs and PWR, but the CANDU fuel is enriched to a lesser degree. Additionally, zircalloy is used as the fuel cladding, as used for Sizewell B's fuel. Therefore, a future CANDU system would not introduce new waste types. In the case of the ACR-700, which is more compact than Sizewell B, less decommissioning wastes would result.

However, if novel materials were proposed their impact on geological repository safety would have to be evaluated early in the decision-making process when reactors designs were being developed and considered. The rigorous assessment processes developed by countries for assessing suitability of radioactive wastes would need to be followed once it was known what reactors were being considered, what materials used etc.

5.5 Repository design implications

The Nirex phased geological repository concept for ILW and some LLW was discussed in section 3.3.2 which also noted that a concept for HLW/spent fuel has been developed. The impact on the reference HLW/spent fuel concept is presented in Table 13.

The impact from 10 new AP 1000s on repository footprint has been assessed based on waste being emplaced 50 years after the spent fuel has been removed from the reactor. The increase on a stand alone HLW/SF repository footprint would be slightly less than the 87% increase in the number of canisters; the increase on a stand alone ILW repository footprint would be slightly less than the 2.5% increase in the volume noted in Table 11; the impact on the footprint of a co-located ILW and HLW/SF repository would be to increase the repository footprint by about 50% above that for current ILW/LLW and HLW/SF volumes.

5.6 Implications of burning plutonium in new reactors

Should new nuclear power reactors be built in the UK, their use could be considered to manage the plutonium stockpile through the burning of mixed oxide fuel (MOX) or inert matrix fuel (IMF). MOX comprises PuO_2 (5%) and depleted uranium oxide. IMF (exclusion of U-238) comprising Pu in an inert matrix, hence no fresh uranium or Pu would be produced in the reactor. It should be noted that in burning Pu as MOX, the uranium in the fuel will produce more Pu, and hence the Pu would not be destroyed completely. British Energy advised CoRWM [46] that separated plutonium could in principle be used in the manufacture MOX for Sizewell B and AGRs, although the commercial case has made it unattractive. New nuclear power reactors, depending on design, could also use MOX fuel, but at today's uranium prices, burning MOX fuel in light water reactors may be uneconomic. Thus existing stocks of separated plutonium would only be used if uranium prices rose, MOX fuel were used as a plutonium management tool, or the fast reactor programme was resumed. It is noted that the overall quantity of plutonium would remain roughly constant (depending on burn-up rates, number of reactors etc.), as separated plutonium would become part of the irradiated spent fuel rather than remain as plutonium oxide.

If a new programme of reactor build were to be undertaken, up to 95% of the UK's plutonium stockpile could be used as MOX fuel, the other 5% remaining as stockpile, and requiring further chemical treatment. Assuming this was in place of "fresh", un-recycled uranium fuel, this strategy would have only a marginal impact on additional wastes generated, and could address some of the security issues surrounding the plutonium stockpile.

Both the AP600 and AP1000, the latest Westinghouse designs of the PWR, have been considered as potential new builds to manage the plutonium stockpile. Studies have indicated that the AP1000 can run on a full core loading of MOX fuel and could convert 95% of the current plutonium stockpile into spent fuel. (See for example the CoRWM position paper on plutonium [[63]] and the February 2005 note by the Parliamentary Office of Science and Technology [[64]]). The EPR has been designed to take up to 50% MOX fuel loadings. CoRWM inventory studies [[46]] said that there could be a potential reduction of up to 3,270m^3 of Plutonium and up to 6,840m^3 of uranium if that was used in MOX fuel.

Spent MOX or IMF fuel has a higher heat output than spent UO_2 fuel. Whilst deep geological disposal of spent MOX fuel is feasible, it would have implications for a repository design, and would need to be taken into account at the design stage. This would also be true for interim storage.

5.7 Decommissioning implications

The AP1000 design has a nuclear steam supply system power rating of 3415MW(t), with an electrical output of at least 1000MW(e). The design life is 60 years without a planned replacement of the reactor vessel. However, the design provides for replaceability of other major components, e.g. the steam generator.

The AP1000 comprises two heat transfer circuits, each containing a steam generator, 2 reactor coolant pumps, one hot leg, and two cold legs. This can be compared with a standard 4-loop PWR comprising 4 steam generators, 4 hot legs, and 4 cold legs. Hence for an AP1000, there is a reduction in components of two steam generators plus associated pipe-work. There are a number of design factors which the manufacturer argues will lead to significantly simpler, quicker and cheaper decommissioning for the AP1000.

These are:

- Reduced number of components through advanced design. The AP1000 design has between 35% (e.g. pumps) and 80% (e.g. heating, ventilation and cooling units) fewer pieces of equipment than for example the Sizewell B design; and
- Modular construction simplifies decommissioning.

The EPR is rated at 4500MW(t), with an electrical output of 1600MW(e), and is based on an evolutionary PWR design with a number of enhanced design features. The design life is 60 years. The EPR comprises a four-loop system each containing a steam generator, a hot leg and a cold leg. In an early study of wastes from future LWRs, it was concluded that differences in the designs of eight PWRs and one BWR, including EPR, had no major implications for the UK waste management policy [[65]].

5.8 Reprocessing and recycling

A number of the reactor types considered in the Generation IV Forum specifically require the reprocessing of spent fuel to recycle nuclear materials into a new fuel. More generally, a significant increase in the use of nuclear power across the world might make recycling a necessity for security of supply and economic reasons.

Evaluation of the nuclear fuel cycle represents a key component of the overall evaluation of possible future reactor types. One possibility that is being considered is to sue "dry reprocessing" technologies that do not involve dissolving the spent fuel in large volumes of aqueous and/or organic solutions, with the associated issues of managing liquid effluents. As noted in Section 3.6, the development of new reprocessing methods in association with new build would allow consideration of the integration of partitioning and transmutation technologies as a means of managing the long-lived radionuclides produced in the fuel cycle.

5.9 Waste management cost and funding implications

5.9.1 Waste management costs

An NEA study [[66]] concluded that except for gas-cooled reactors, the type of reactor does not seem to significantly affect decommissioning costs on a unit cost per kW(e) installed capacity basis. For all water reactors for which data were available, the cost per kW(e) installed capacity appeared reasonably independent of reactor type, and the capacity effect, although noticeable, was not significant. The average cost of PWR decommissioning plus one standard deviation was $515 per kW(e), or about £291 per kW(e). On the basis of a 1600 MW(e) unit, the decommissioning costs would therefore be about £466M.

The BNFL decommissioning cost estimate [[67]] for the AP1000 is £0.6/MWh electricity output. On the basis of one 1200 MW(e) unit operating for 50 years, the decommissioning cost estimate would be about £525M. An Oxera study [[68]] for decommissioning costs estimated £210/kW(e) assuming a 3.5% discount rate, and this corresponds to a cost of £252M for a 1200 MW(e) unit. It is to be expected that cost estimates will vary significantly owing to the uncertainties and methods used in the calculations. Taking these aspects into account, the two estimates are in reasonable agreement.

It has been claimed that whilst the waste management policy issue needs resolution, the financial impact of waste management and decommissioning is minimal [[69]].

In terms of impact on repository costs, section 3.7.2, indicated that a standalone ILW/LLW repository has a lifecycle cost of about £6.3bn, that for a standalone HLW/SF repository of £4.9bn and for a co-located facility a cost of £8.2bn. The impact on costs of 10 new AP1000 new build programme assumes that the variances are additional to an ILW repository and a separate HLW/SF repository as identified in [[70]].

The volume of additional ILW is small as a result the variable costs for small volume variations can use the marginal cost of £4k/m^3 of conditioned waste. The additional cost for ILW is therefore c. £30 million (£4k/m^3 x 8,000m^3). This value does not include any estimate for uncertainty but it is considered that it will not significantly increase the overall risk estimate assumed for an ILW repository of £1.2 billion.

The cost impact of HLW is zero as it is assumed that no reprocessing will take place and all spent fuel from 10 new AP1000 stations will be disposed of directly.

Using the variable cost estimation for HLW/SF of £278k per canister, the additional cost of 10 AP1000s would be £2 billion (£278k x 6673 extra canisters). This value does not include any estimate for uncertainty but is considered to be of the same order as that for an ILW repository.

5.9.2 Financing

As noted in section 2.3, Government policy states that any new nuclear facility should be designed and built so as to minimise decommissioning and associated waste management operation and costs. This approach will ensure that the UK minimises the creation of decommissioning liabilities for future generations.

If there were a decision to proceed with a programme of new reactor build there are a number of scenarios for how that programme might be delivered and funded. The issues surrounding each are outside the scope of this report. However, a new build programme could be implemented through the public sector, private sector or a combination of both.

The long term liabilities associated with waste management and decommissioning have in the past been a significant hurdle for private investors. If any future programme were to involve private finance, it might be considered possible that there may be some level of Government involvement to give confidence that these risks would be on a basis for which the private sector could make appropriate arrangements, whilst taking into account any relevant European legislation on competition or state aid (see section 4.1).

Any operator of any new power station would need to have fully developed and funded plans for the waste management and decommissioning activity both in order to obtain an operating license and funding. It is clear that the costs and liabilities of waste management and decommissioning of new reactors would need to be fully taken into account on any programme of new build.

It is possible that future decommissioning and waste management costs could be covered by nuclear operating companies being asked to pay a proportion of operating income each year into a fund to ensure money was available.

6 TABLES AND FIGURES

Box 1: Description of radioactive wastes

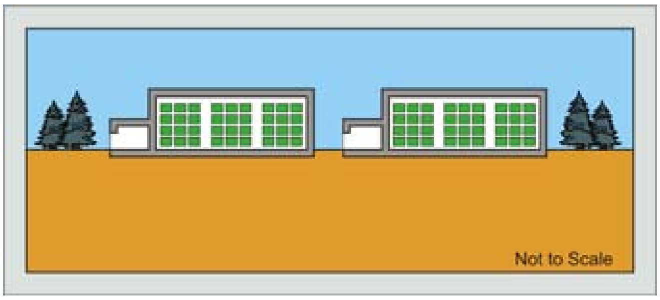
High Level Wastes (HLW) Wastes in which the temperature may rise significantly as a result of their radioactivity, so this factor has to be taken into account in the design of storage or disposal facilities. Initially HLW comprises nitric acid solutions containing the waste products of reprocessing spent nuclear fuels.

Intermediate Level Wastes (ILW) Wastes exceeding the upper boundaries for LLW, but which do not require heat to be taken into account in the design of storage or disposal facilities. The major components of ILW are metal items such as nuclear fuel casing and nuclear reactor components, graphite from reactor cores, and sludges from the treatment of radioactive liquid effluents.

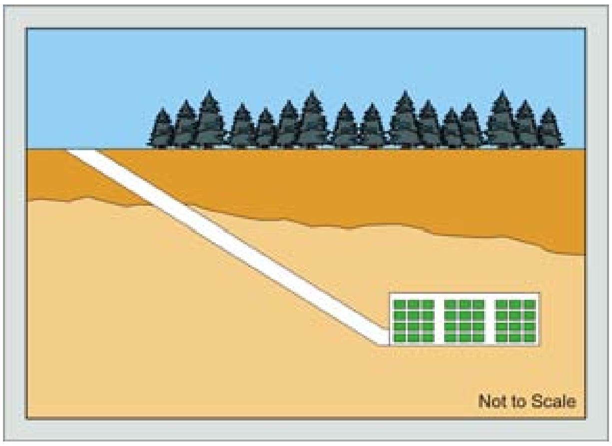
Low Level Wastes (LLW) Wastes other than those suitable for disposal with ordinary refuse, but not exceed 4GBq/te alpha or 12GBq/te beta/gamma activity. Overall, the major components of LLW are soil, building rubble and steel items such as ducting, piping and reinforcement from the dismantling and demolition of nuclear reactors and other nuclear facilities and the clean up of nuclear sites. However, at the present time most LLW is from the operation of nuclear facilities, and this is mainly paper, plastics and scrap metal items. A sub-category of LLW is Very Low Level Waste (VLLW, <0.1m^3 with low activity - <400kBq), which arises mainly in small volumes from hospitals and universities. It is disposed of to landfill, either directly or after incineration, under an appropriate regulatory regime. VLLW is not included in the National Inventory.

Figure 1: CoRWM's shortlist of options (7 images)

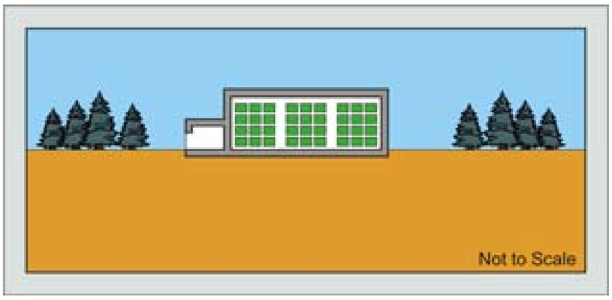
1. Interim storage above ground at central locations



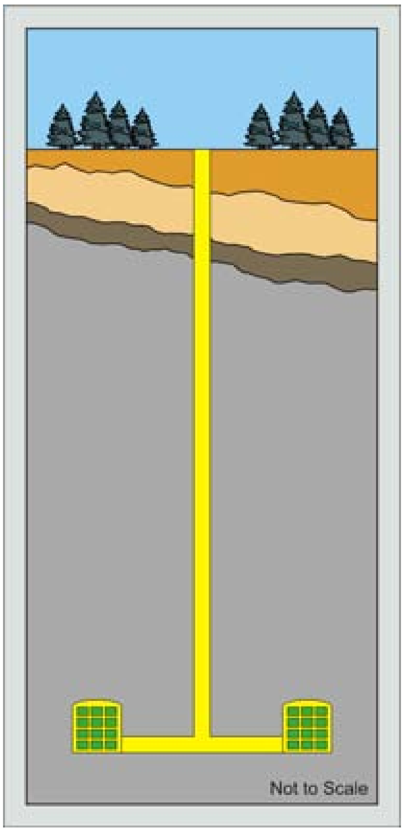
2. Interim storage below ground at central locations



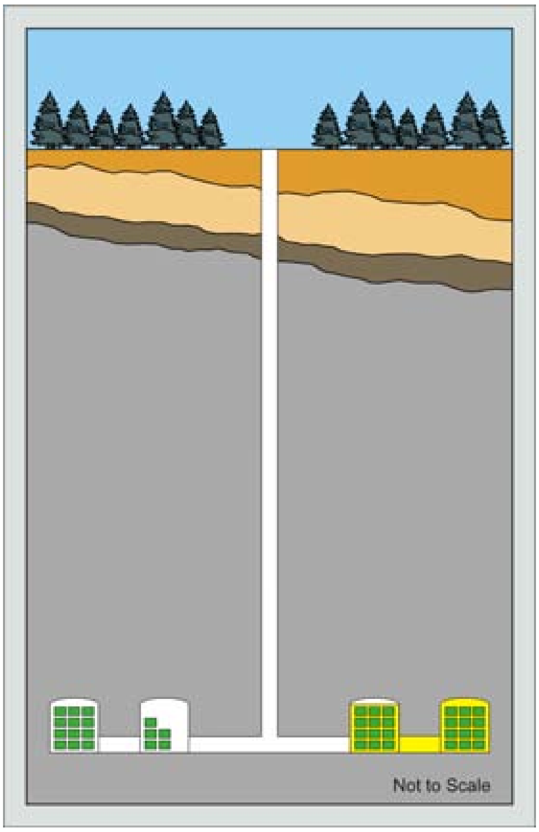
3. Interim storage above ground at or close to existing nuclear sites



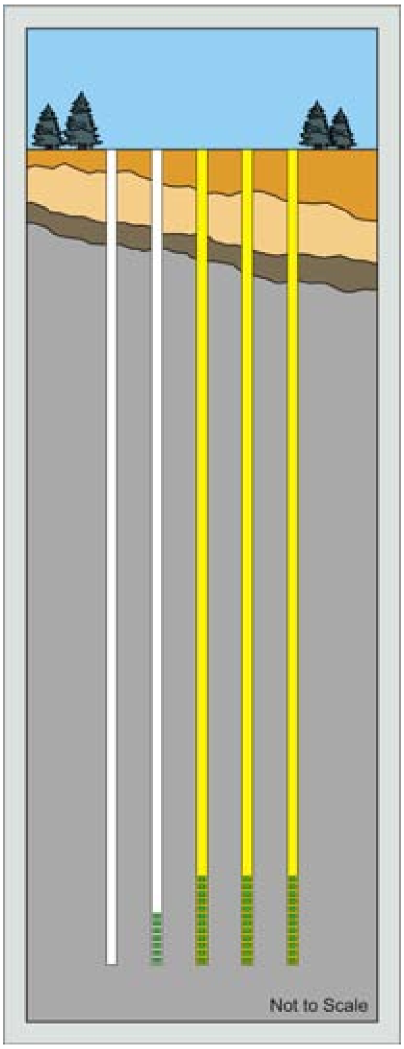
4. Deep geological disposal at a central location



5. Phased geological disposal at a central location



6. Deep boreholes at a central location



7. Non-geological disposal at or close to existing nuclear sites

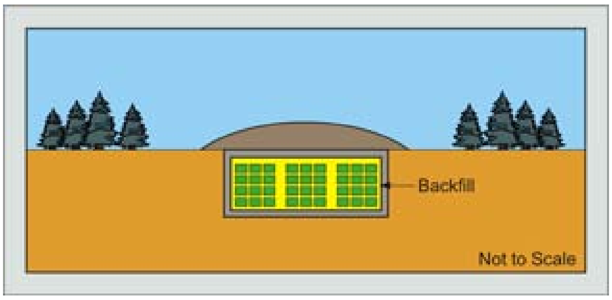


Figure 2: Overview of decision-making process using SEA and EIA

Figure 3: The phased geological repository concept

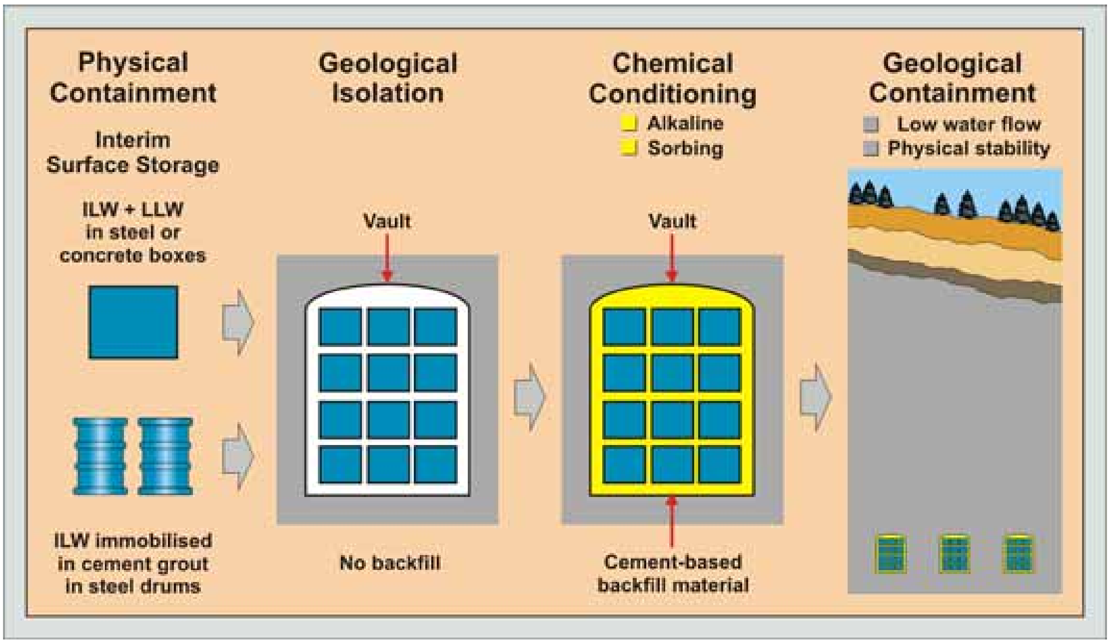


Figure 4: Decommissioning of Vandellós I nuclear power plant, Spain (Courtesy ENRESA)

1. General view during operation

2. Dismantling operations

3. Reactor underside

4. Waste sorting

5. Safe enclosure

6. View of Vandellós I and II

Table 1: Managing Radioactive Waste Safely – illustrative timetable (amended)

Stage 1	The consultation on process, consideration of responses, planning the next stage.	2001-02
Stage 2	Research and public debate to examine the different options and recommend the best option (or combination). Government decision on option(s) to implement.	2002-06
Stage 3	Consultation on how the preferred option(s) should be implemented.	2007
Stage 4	Implementation including legislation, if needed.	2008 onwards

Table 2: Stages in the SEA process mapped onto the radioactive waste management process

Stage in SEA process	Action relating to radioactive waste management	Organisation responsible
Stage A: Setting the context and objectives, establishing the baseline and deciding on the scope	National consultation on the site selection process including the siting criteria, the roles and responsibilities of organisations, local community power in the decision-making process and community benefits.	Government or Overseeing body
Stage B: Developing and refining alternatives and assessing effects	The siting criteria and process are applied by the implementer to the UK to assess sites and identify a potential short-list of sites to be evaluated in an EIA.	Implementer
Stage C: Preparing the Environmental Report	A report (Sustainability Appraisal) of the assessments is written, including a summary report.	Implementer
Stage D: Consulting on the draft plan or programme and the Environmental Report	A national debate to review the Sustainability Appraisal.	Government
Stage E: Monitoring the significant effects of implementing the plan or programme on the environment	Processes will need to be put in place to monitor the implementation of the programme and ensure and adverse environmental impacts are mitigated.	Government

Table 3: Stages in the EIA process mapped onto the radioactive waste management process

Stage in EIA process	Action relating to radioactive waste management	Organisation responsible
Scoping	Consultation on the scope of the Environmental Impact Assessment, what should be assessed and how and how stakeholders should be involved.	Implementer
Assessment	The short-list of sites are assessed against the agreed criteria to identify a preferred site.	Implementer
Writing environmental report	A report (Sustainability Appraisal) of the assessments is written, including a summary report.	Implementer
Environmental impact assessment report review	A national debate to review the Sustainability Appraisal.	Government
Decision	Government will decide whether to approve implementation of the facility at the recommended site	Government
Implementation and monitoring	The implementer will construct the facility and the Government will ensure appropriate monitoring is undertaken.	Government

Table 4: Baseline volume changes for different scenarios

Scenario		Volume change for waste type (m^3)				
		Spent fuel	HLW	ILW	Plutonium	Uranium
Baseline	Volume	8,150	1,290	353,000	3,270	74,950
	Activity (TBq)	33 x 10^6	39 x 10^6	2.4 x 10^6	4 x 10^6	3,000
Reprocess remaining 3,500tU AGR SF		-5,410	+250	+7,000	+580 (18te)	+1,660 (3,390tU)
Reprocess 1,200tU Sizewell B PWR SF		-2,740	+90	+2,000	+450 (14te)	+550 (1,120tU)
No substitution for overseas wastes with return of ILW			+60	-5,000		
Decay storage / decontamination (waste producer plans)				-19,000		
Segregation of ILW and LLW in cases where they are mixed and disposal of LLW				-4,500		
Extend AGR lifetimes by 5 years (1,320tU fuel not reprocessed)		+840		+4,100		
Extend Sizewell B PWR lifetime by 10 years (300tU fuel not reprocessed)		+680		+170		
Early closure of Magnox reprocessing / Magnox reactors			-160	–8,800	–640 (20te)	– 3,390 (6,940tU)
Early decommissioning of nuclear power reactors				+17,580		
Early closure of THORP			-250		-580 (18te)	-1,660 (3,390tU)
Unaccounted SSRSs				+<10		
10 x AP1000 reactors		31,900 (14,000tHM)		+9,000		
Use of UK separated Pu/U in new build MOX					-3,270 (105te)	–6,840 (14,000tU)

Table 5: Summary costs for CoRWM short-listed waste management options[53]

Option		Cost
1	Long term interim storage and its variants:	
	Local, above ground, protected	£14.5bn (L)
	Local, above ground, unprotected	£7.5bn (L)
	Local, below ground, protected	£12.5bn (M)
	Centralised, above ground, protected	£12bn (L)
	Centralised, above ground, unprotected	£6.5bn (L)
	Centralised, below ground, protected	£7.5bn (M)
2	Deep geological disposal:	
	Deep disposal	£9.5bn (M)
	Disposal in boreholes (HLW,SF, Pu)	£5.5bn (H)
3	Phased deep geological disposal	£13bn (M)
4	Non geological disposal (near surface) for reactor decommissioning wastes only:	
	Engineered vault, local to current wastes, protected	£0.2bn (L)
	Engineered vault, centralised, protected	£0.125bn (L)
	Mounded over reactors	£3bn (H)
	Below ground disposal	£0.2bn (M)

Table 6: Stand-alone ILW / LLW repository programme and costs

Cost component	Costs (£m)	End date
Sunk costs	700	
MRWS	50	2007
Site characterisation	910	2020
Construction and underground research	1940	2040
Operations of facility (includes further construction)	1830	2090
Care and maintenance	510	2140
Closure	250	2150
Total	**£6.2 billion**	

Table 7: Stand-alone HLW / Spent fuel repository programme and cost estimates

Cost Component	Cost (£m)	End date
Site characterisation	920	2007-2020
Construction and underground research	1600	2040
Operations of facility (includes further construction)	2100	2090
Closure	315	2100
Total	**£4.9 billion**	

Table 8: Co-location of ILW/LLW with HLW/spent fuel repository programme and cost estimates

Cost Component	Cost (£m)	End date
Sunk costs	700	
MRWS	50	2007
Site characterisation	1050	2020
Construction and underground research	2470	2040
Operations of facility (includes further construction)	3040	2090
Care and maintenance	530	2140
Closure	330	2150
Total	**£8.2 billion**	

Table 9: NDA Decommissioning, clean up and operating cost estimates by site

Sites		£m		
		Decommissioning & clean-up costs	Operating costs	Total cost
Magnox	Berkeley	823		823
	Bradwell	1,129		1,129
	Chapelcross	1,663		1,663
	Dungeness	1,035	128	1163
	Hinkley	1,130		1,130
	Hunterston	1,214		1,214
	Oldbury	1,155	213	1368
	Sizewell	1,099	139	1238
	Trawsfynydd	1,116		1,116
	Wylfa	1,221	489	1710
UKAEA	Culham	196		196
	Dounreay	2,908		2,908
	Harwell	918		918
	Windscale	662	8	670
	Winfrith	461		461
British Nuclear Group	Drigg	1,340		1,340
	Calder Hall	1,284		1,284
	Sellafield	23,650	7,895	31,545
	Capenhurst	1,145		1,145
Westinghouse	Springfields	461	2,370	2,831
Total		**44,610**		**55,852**

Table 10: Waste volume arisings for 10GW(e) installed capacity[iv]

Reactor type x number 10GW(e) eq.	Spent fuel (tHM)	Packaged volume (m^3)		
		Fuel in SKB canisters	ILW	LLW
AP1000 x 10	14,000	31,900	9,000	80,000
EPR x 7	9,200	21,000	13,000	100,000
ABWR x 8	15,400	31,500	187,000	
PBMR x 98 modules	6,200	130,000[v]	10,800[v]	

[iv] Neither the figures for legacy nor new build wastes include depleted uranium that has been or would be generated in the fabrication of fuel.
[v] Assumes 460m^3 of HLW would be returned overseas.

Table 11: Waste volume increases for 10 x AP1000 reactors[iv]

Scenario		Packaged volume (m^3)			
		Spent fuel	HLW	ILW	LLW
Baseline		8,150 (CoRWM) 6,700 (Nirex)	1,290[v]	353,000	2.48 million + 37,200 (non-Drigg)
AP1000 x 10	m^3	31,900 (CoRWM) 20,000 (Nirex)	-	9,000	80,000
	% increase	390% (CoRWM) 300% (Nirex)	0%	2.5%	3%

Table 12: Activity increases for a new build of 10 x AP1000s

Scenario	Year	Activity (TBq)			
		Spent fuel	HLW	ILW	Total
Baseline[vi]	2090	$6.0x10^6$	$1.4x10^7$	$1.1x10^6$	$2.0x10^7$
AP1000 x 10[vii]	2090, 10 post removal	$1.8x10^8$ 3000%	-	$8.7x10^4$ 8%	$1.8x10^8$ 900%
	2130, 50 post removal	$6.0x10^7$ 1000%	-	-	$6.0x10^7$ 300%
	2180, 100 post removal	$1.8x10^7$ 300%	-	-	$1.8x10^7$ 90%

Table 13: Impact of new build on number of canisters to be handled

Scenario	Number of canisters			
	AGR spent fuel	PWR spent fuel	HLW	Total
Legacy	3,398	572	3,700	7,670
AP1000 x 10	-	6,673	-	6,673
Total				14,343
% increase				87%

[vi] ILW inventories based on 2001 Inventory [[37]] (ILW from AP1000 estimated as a ratio of ILW from PWR Sizewell B). HLW/SF inventories based on reference [[40]].
[vii] Based on the 2001 inventory data in Reference [[46]]. This has also been compared against the recent 2004 Inventory information and found to be very similar.

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