Abstract (100-200 words as desired):

The project has provided a broad-brush view of the current knowledge of 14 long-term radioactive waste management options and five actual or potential waste categories. It then examines policy and regulatory principles, national and international agreements and legislation, public acceptability and the perspectives of environmental interest groups. Generic questions were developed and posed for all 14 options, and, with other attributes, were assigned to 630 work packages based on the methodology used in ‘An R&D Strategy for the Disposal of High-Level Waste and Spent Fuel’, DETR/RAS/99.016, October 1999. These work packages define the information which must be gained before any option could be adopted with confidence. The projects then suggests a methodology by which the work required may be prioritised to allow a number of the options to be excluded early in the process, enabling a manageable overall programme to proceed. Throughout, the project emphasises the need for an holistic process, carried out in an open and transparent manner with extensive stakeholder involvement at every stage.
Keywords: Radioactive wastes, management options

The results of this work will be used in the formulation of Government policy, but views expressed in this report do not necessarily represent Government Policy

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Executive Summary

1. In September 2001, the Department for Environment, Food and Rural Affairs (Defra) and the Environment Departments of the devolved administrations for Scotland, Wales and Northern Ireland issued a consultation paper ‘Managing Radioactive Waste Safely’ (MRWS). The paper proposed a programme of action for deciding how to manage UK solid long-lived radioactive waste in the long term. It also identified the need for research into the potential options for managing the wastes, including an assessment of the current knowledge base and an identification of gaps in knowledge.

2. This project, called the Information Needs Research Project, which is reported here, was commissioned to provide a broad-brush view of current knowledge about long-term management options for such wastes. It is anticipated that this final report of the Information Needs Research Project will assist with further stages in the MRWS programme.

3. In the specification for this current project the contractor was required to satisfy a number of specific objectives:

   - Identify the range of radioactive waste management options for UK solid long-lived radioactive wastes;
   - Identify, for these options, the detailed information which will be required by the Government, after due consultation, in order to select, with confidence, practical management options;
   - Identify, for these options, those where we currently have the information and those where at least some information is currently lacking or imprecise;
   - Outline the future studies necessary, with estimates for staff and time resources required, to obtain the lacking information and improve the precision of uncertain information before the decision point is reached;
   - Assess the importance of what will not be known and may remain unknown.

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2 Defra News Release 315/02, 29 July 2002
4. The Project was undertaken by Wilkinson Environmental Consulting Ltd. It was peer reviewed and guided by a group of experts/stakeholders appointed as a Steering Group. While this report identifies major issues that need to be addressed during the full implementation of an option, it does not endorse one option over another but identifies potential weaknesses in one option compared to another. The final endorsement of option(s) is for Ministers, whilst most of the research needed to implement the option(s) will be specific rather than generic, and carried out during the implementation period, which could last for decades. This report advises what information needs to be obtained and how this might be done during the review and implementation phases.

5. In Section 2 of this report the properties of five UK waste or potential waste types, namely high level waste (HLW), intermediate level waste (ILW), spent fuel, plutonium, and reprocessed and depleted uranium are reviewed. Then the UK radioactive waste inventory and the risks posed by radiation are examined so as to provide the context for the work on long-term management. Section 3 identifies 14 potential waste management options, giving a general overview of each and highlighting key points to be considered during the assessment of the information needs of the options. The report in Section 4 provides a broad examination of the interaction between radioactive waste management policy and other areas of Government policy, environmental principles and societal concerns. Additional sections cover legal aspects (national, European and international law in Section 5), general scientific and technical aspects (Section 6), public perception (Section 7), and perspectives of environmental interest groups (Section 8).

6. Having reviewed the principal areas relevant to radioactive waste management policy making and having defined the options to be considered, the report presents in Sections 9 and 10 and associated Appendices an analysis of work packages that would need to be carried out to meet the information needs and related activities for each option. Section 11 comments on responses to the MRWS consultation programme. In Section 12 a manageable process for taking forward the information-gathering element of the programme announced by the Government on 29th July 2002 is suggested. Full details of the key questions and the 630 potential work packages derived to cover all 14 options are provided in Appendices. The word ‘potential’ is important as, when taking the MRWS process forward, it should be possible in later stages to remove some options, and hence work packages, from consideration at an early stage. Most work packages will be for the implementation stage and could take many decades to complete.

7. The project commenced with a literature survey and information gathering phase, followed by a general review of the long-term waste management implications of Government policy and principles, law, science and technology, and public acceptability. Subsequently, the project examined the parameters describing individual management options and their information needs.

8. All the fourteen waste management options were reviewed for the five waste or potential waste types set out in paragraph 2 above. The options were: -
1. Above ground storage
2. International above ground storage
3. Underground storage
4. International underground storage
5. Underground disposal
6. International underground disposal
7. Direct injection – injection of waste as liquid into deep geological strata.
8. Disposal at sea – disposal onto the sea bed
9. Sub-seabed disposal - disposal in sediments beneath the sea bed
10. Disposal in ice sheets
11. Disposal in subduction zones - disposal at tectonic plate boundaries.
12. Partitioning and Transmutation – the transformation of long-lived substances into shorter-lived or more stable forms.
13. Disposal in space
14. Dilute and Disperse - diluting and dispersing into the general environment

It is accepted that there are other options / variations but that the information needs are likely to be very similar to those already identified.

9. In the second phase a methodology was developed to define the information needs of all these management options. This was based on the similar task performed in the 1997-99 project ‘An R&D Strategy for the Disposal of High-Level Waste and Spent Fuel’\(^3\). That project had identified the information needs for one management option (geological disposal) of one waste (HLW) and one potential waste type (Spent Fuel), together with some consideration of plutonium, uranium and ILW. That project identified more than 60 work packages to meet the policy and technical milestones of completing this scenario i.e. to the point of closure of the repository, a process of many decades duration. It should be emphasised that though that earlier project acted as a framework, the current project team considered all 14 waste management options equally within its methodology.

10. In order to arrive at a point where information needs could be identified, the project team assembled a set of generic questions that could be addressed across the range of options. The questions included, either directly or indirectly, all the criteria suggested by the Government’s Radioactive Waste Management Advisory Committee (RWMAC) in their recent review\(^4\). The questions were grouped into four sets covering

- Laws, Treaties and Obligations
- Principles and Government Policy
- Scientific and Technical Aspects

• Public Acceptability

This process generated 47 questions. These were then posed for all 14 options.

11. In addition to the 658 answers to the generic questions, key points from each option were separately identified. Sets of key questions were also generated from the literature survey and information gathering phase. All these answers, key points and key questions, (collectively called “attributes”) were then assigned to individual work packages derived from the relevant HLW and Spent Fuel Project work packages. Some attributes were not covered by the scope of these earlier work packages and so new work packages were devised to satisfy these. This led to a complete work package and attribute listing for all options and to the identification of 630 potential work packages.

12. One important purpose of the INRP work packages is to identify ‘areas of learning’ needed for the selection of practical options ‘with confidence’. Identification alone is not enough, however. It is also necessary to ensure that the information gained becomes part of an integrated process design, which involves relevant stakeholders and the public, so that it becomes a credible step towards having ‘sufficient knowledge to proceed with confidence’. The issue of confidence is particularly important in the case of radioactive waste management because of the extremely long timescales involved. It is as much related to the confidence in the institutions involved in the decision making process as it is to the science and technology to be deployed.

13. For any option to be implemented, it must necessarily meet appropriate national and international safety and legal requirements. The activities necessary to achieve this are contained in the work packages. The current Government policy review may only need to establish that on balance an option or combination of options is clearly ahead of other options/combinations and that there is a strong enough probability that it will meet the necessary standards to proceed with confidence. This is because all the waste- and site-specific circumstances cannot be known in advance of a specific scheme being defined. Much further work on meeting all appropriate requirements must then be done while the chosen policy is being implemented, possibly over a period of 25 years or more.

14. Safety is a key factor in undertaking any human activity including waste management. Safety might be thought of as a potential ‘show stopper’ where the generic safety case for a chosen option cannot be made with sufficient confidence. Other areas, such as technology, cost, legal restrictions, or political and diplomatic difficulties provide additional hurdles for the various options, some of which may be insurmountable.

15. During the course of the current project, at the suggestion of contractor, and with the agreement of the Steering Group, Defra asked the contractor to modify the project objectives and to extend, for completeness, the work packages to include all options e.g. including even those ruled out by international agreements. While the earlier HLW and Spent Fuel project produced work packages with outline timescales, and classification was into broad work content bands, it did not estimate the effort required or the cost of the work packages. The project team also felt unable to
estimate effort and costs, given the breadth and complexity of the current potential work packages related to generic options. This project has also not considered the possibility of different waste management options being adopted for the various waste streams, as the number of permutations becomes unwieldy. This added complication should, however, be addressed as part of the ongoing process of policy formulation.

16. The 630 potential work packages and the complexities and uncertainties outlined above, suggests to the team that pursuing all waste management options in parallel to the same level of detailed consideration would not produce a practical or manageable programme. The effort and expertise required cannot be delivered against the programme envisaged in the Government's MRWS consultation. Additionally it must be questionable whether most stakeholders and the general public would view it as good value for money to spend several £ millions and decades assessing, for example, some options which have no serious prospect of being implemented.

17. The project team, therefore, recommends that any process embarked on should be able to prioritise work packages in an open and transparent manner so as to produce a more sensible and manageable overall programme. The work done under the project and the team’s background knowledge leads to the view that many potential work packages for some options either involve disproportionate resources or have limited prospects for a successful outcome or both.

18. The process of prioritisation might usefully start by identifying those options likely to produce extreme results such as very high costs, inadequate safety assurance, or incompatibility with key national policies or international agreements. Options could be legitimately excluded if a broad agreement were achieved that such outcomes preclude further detailed study of the option. Extracts from Appendix 17, which provides an example of how this might be done, are included below.

<table>
<thead>
<tr>
<th>Key Generic Question</th>
<th>Option A</th>
<th>Option B</th>
<th>Option C</th>
<th>Option D</th>
<th>Option E</th>
</tr>
</thead>
<tbody>
<tr>
<td>2g Is the predicted safety or environmental detriment in line with regulatory standards? Safety assurance difficult</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2r Is current waste policy and practice precluding or reducing the scope for selection of this option? Timescale and current waste conditioning practices limit applicability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2k Is the cost likely to be a determinant? High cost options</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3f Does the option crucially depend on future technological innovation? Challenging/high risk technology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
If the option is prohibited by international treaty, is it feasible to contemplate renegotiation? *Extreme political/diplomatic challenge*

Does the option apply to all wastes? *Applicable to limited number of waste types – implies the need for more than one option to be adopted*

Does the option rely on institutional survival? *Not deemed an ethical solution*

Are there examples in other countries or natural analogues that can increase assurance? *UK ‘go it alone’ not feasible*

Does the option allow the long-term retrievability of the waste? *No*

19. This table presents a selection of the 47 generic questions applied to an undefined selection of the 14 waste management options. The shaded boxes indicate that the amount of work required is likely to be disproportionately large, or that the ‘answers’ arrived at are very probably to be unfavourable to the option. Example ‘answers’ are shown in italics. This allows an initial view to be taken of the relative feasibility and practicability of each option.

20. From this analysis it is suggested the following process stages could be included in any review of options:

i. Identify a few questions (and therefore a few potential work packages) where it can be easily demonstrated that the answer is highly disadvantageous to one or more of the options

ii. Seek transparent and sufficient agreement that these particular factors are sound reasons to exclude one or more options.

iii. Reduce the number of options being evaluated.

iv. Review remaining potential work packages with a view to providing enough information to justify further decision points and option reductions.

21. Once this prioritisation process is underway, it should be possible to review those work packages that remain relevant, with a view to grouping them and refining the level of definition and timing appropriate for having the work performed. Many of the work packages for the chosen options will need to be undertaken over an extended period of time once the decision is made to implement them.

**Additional commentary**

22. The process by which the policy for the long-term management of long-lived wastes is developed will not take place in a vacuum. In the meantime, ILW is being conditioned to Nirex specifications predicated on storage followed by geological disposal, while the HSE Nuclear Installations Inspectorate anticipates waste producers managing wastes for interim storage periods of up to 150 years. There is therefore a need to ascertain whether this timeframe for interim storage is an acceptable background to the process of choosing ‘practical management options for solid long-
lived radioactive wastes’. In particular:

- Is an emphasis on moving as soon as is reasonably possible to passive, safe, monitorable and retrievable interim storage a suitable policy for untreated waste?
- Is an overall period of interim storage of up to 150 years a suitable planning basis for radioactive waste being placed in storage now?
- Should deep geological disposal still effectively define the specification for ILW to be treated for storage or could a more general specification covering a number of options be found?

23. These questions need to be answered well in advance of the policy envisaged by MRWS being defined, and present an urgent area for policy decision.

24. Other policy and regulatory developments will interact with the process. In addition to the plans for the Liabilities Management Authority, there are a number of key regulatory consultations and outstanding policy issues which will impact upon the technical implementation and therefore the public acceptability of the various options outlined in this report. On July 29 2002 the Government announced\(^2\) the outcome of the MRWS consultation and what it intended to do next. There should therefore be a work stream to determine the interaction between these various statements and consultations and any additional information requirements that could emerge.

\(^2\) Defra News Release 315/02, 29 July 2002
In addition to the diligence, help and advice from those directly involved in the project (see Section 1.6 paragraph 5 and Appendix 4), Wilkinson Environmental Consulting would like to thank for their help:

Steve Crossley and Kevin Hesketh of BNFL Springfields for the Instantaneous Toxic Potential computer runs and resulting figures (see Section 2.2), and to Dr Sue Ion for sanctioning the work

Anne Claudel of NAGRA, for considerable help with the bibliography section

Malcolm Wakerley of DEFRA for accessibility and diligence as our primary contact with the customer.
1. Introduction and Project Scope

1.1 Project Background

1. The objectives of the research project are to:

- Identify the range of (radioactive) waste management options

- Identify, for a range of options, the detailed information which will be required, by the Government after due consultation, in order to select with confidence practical management options for solid long-lived radioactive wastes

- Identify, for those options, those where we currently know the information and those where at least some information is currently lacking or imprecise

- Outline the future studies necessary, with estimates for staff and time resources required, to obtain the lacking information and improve the precision of uncertain information before the decision point is reached

- Assess the importance of what will not be known and may remain unknown.

2. The scope of the work calls for

- a review of all options which have been proposed for long-term management of long-lived wastes, noting the differences in management needs – see Section 3

- the identification of those options which fall foul of current national or international legislation – see Section 5

- the identification, for those options remaining, all ‘areas of learning’ needed for the selection of practical options with confidence – see Sections 8 and 9

- an assessment of the safety impact of these options on current and future generations – see Sections 8 and 9

- the identification of the source of information available both in the UK and abroad and where information is lacking or imprecise –see Sections 8 and 9

- an outline of future studies necessary to improve the imprecision before a decision point is reached and to estimate the staff and time resources required to achieve this – see Sections 8 and 9

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3 This element of project scope was changed by agreement with DEFRA and Steering Group – see Section 1.2 paragraph 7, bullet 2.

4 In order for any option to be implemented, it must necessarily meet appropriate national and international safety standards. This element of project scope has been delivered by assessing the activities and deliverables necessary to achieve this.
• the examination of responses to the Government’s consultation programme\(^5\) and to note that the areas of learning may include disciplines beyond engineering and science to embrace, for example, political, economic and sociological concerns – see Section 10

• liaison with other agencies knowledgeable in the field – see Section 1.6.

1.2 Development of Project Scope

1. In September 2001, the Department for Environment, Food and Rural Affairs (DEFRA) and its sister Environmental Departments in Wales, Scotland and Northern Ireland, published ‘Managing Radioactive Waste Safely (MRWS) – proposals for developing a policy for managing solid radioactive waste in the UK’ as the Government’s background to the radioactive waste public consultation programme. This five stage programme was scheduled to conclude in 2007 and was preceded by a review stage conducted by the House of Lords Select Committee on Science and Technology when it examined the issue from November 1997 to March 1999.

2. On commencement of the work associated with the research contract (known as the Information Needs Research Project – INRP), a work plan or Gantt chart was submitted to DEFRA personnel for approval. After a few minor iterations, this work plan was accepted and is attached at Appendix 1.

3. Additionally, the methodology to be pursued in the execution of the research project was drawn up in a schematic diagram and submitted as part of the tender to DEFRA. This presented a series of ‘horizontal’ work activities which examine the long term waste management implications of Government Policy and Principles, Law, Treaties and Obligations, Science and Technology, and Public Acceptability. Subsequently, ‘vertical’ work activities examined the importance of various factors involved in the individual waste management options. This diagram is attached at Appendix 2.

4. As part of DEFRA’s review and monitoring process for the INRP, it appointed a Steering Group (for membership see Appendix 3) which first met Wilkinson Environmental Consulting Ltd (WECL) principal consultants (see Appendix 4) on the 22\(^{nd}\) November 2001 in DEFRA offices in London. This meeting was designed as a means by which an extended group of experts/stakeholders could critically review not only the work plan and methodology proposed to be used in the project, but also to plan an on-going review schedule. During this review, progress could be monitored and advice offered in order to ensure that the research team had the benefit of the expert input of a wider group.

5. At the initial meeting, the research team made a presentation of their work to date and their plans concerning the methods they would employ in executing the INRP. There was some discussion of the terminology used in framing the objectives of the contract. In particular, the use of the words ‘with confidence’ in connection with the

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\(^5\) It was suggested by DEFRA and agreed by the Steering Group that this element would be delivered by the project team commenting on a DEFRA digest of the MRWS consultation responses.
ability of the Government to make radioactive waste management choices was identified as being a key phrase in that the degree of confidence which the Government sought to achieve would necessarily and unavoidably influence and dictate the level of information required. In short, how much information is required to drive up the level of confidence sought? Secondly, can any amount of information eliminate a lack of confidence? Also, the project objective of assessing ‘the importance of what will not be known and may remain unknown’ can only be evaluated against the background of what is meant by ‘with confidence’. This alone will determine the importance of uncertainty, and this will be affected by the process by which information is integrated into the ongoing policy development process.

6. This led to a discussion about the consultation process itself – rather than the information needed to influence the debate. In particular, the process of engagement, the interpretation of the term ‘public’ and the effort foreseen in conducting a process which would result in public confidence were all identified as issues central to the successful outcome of the project. While these issues remain unresolved to a large extent, it was agreed that the INRP should restrict its work to the provision of information concerning what was available in terms of data and where gaps in that information lie. Nonetheless, an important question remains: what level of confidence does the Government seek to achieve in respect of gaining public acceptance of any future management process? The answer to this question, while it may appear to fall outside the brief of the INRP, remains key insofar as it will determine the level of detail needed to achieve the required degree of confidence, and hence the extent and the scope of the bibliography needing to be examined.

7. Clearly, before embarking on the project, the research team felt the need to seek agreement with DEFRA and the Steering Group as to the assumptions it could legitimately make in terms of waste. These were agreed as follows:

- The starting point for the study (except when considering Partitioning and Transmutation) is the 1998 version of the UK Waste Inventory which contains details of HLW, ILW, LLW and some spent research and early reactor fuels.
- Options falling foul of current national or international legislation would not be removed from further consideration.
- All waste considered would be in a conditioned form equivalent to Nirex ‘letter of comfort’ standards before options are implemented. This is the current arrangement whereby Nirex inform the waste producers that a waste package appears consistent with the requirements for a period of storage, transport, handling, and, potentially, eventual deep geological disposal. It should however be noted that some waste, particularly solid materials such as graphite from Advanced Gas Cooled Reactor (AGR) fuel assemblies, stainless steel grids and contaminated plant items, are currently stored without encapsulation and without being covered by the ‘letter of comfort’ system.
- Waste considered will be that for which long term management options are still undecided, that is Intermediate and High Level Waste (ILW, HLW) plus those which might become classified as waste: surplus plutonium, some reprocessed and depleted uranium, and some spent fuel. Spent Fuel was further subdivided into three to cover the main UK commercial reactor fuels.
The following areas dealt with in MRWS will not be considered: low level waste (LLW), substitution, a general approach to decommissioning, sealed sources and segregation of wastes by half-lives.

LLW which could not go to the national site at Drigg, Cumbria for activity reasons would be included in the study, but it was agreed that this would make no significant volumetric or activity difference to the ILW inventory.

1.3 Delivering the Required Information Needs

1. As stated above, the research team has been tasked to ‘Identify, for a range of options, the detailed information which will be required, by Government after due consultation, in order to select with confidence practical management options for solid long-lived radioactive wastes’. This has been done by generating questions to which answers are required.

2. A key factor to be considered is what level of buy-in from the public will be necessary for Government to select a policy ‘with confidence’. While the project team recognises that the questions generated are not exhaustive, they have been constructed as closed questions demanding a yes/no answer. If questions are overwhelmingly answered in a way favourable to an option, then an option can, by definition, be considered to enjoy a degree of confidence. (NB - depending on the way the question is couched, both affirmative and negative responses can be deemed favourable to particular options). It should be noted also that the ‘with confidence’ condition is relevant across the entire scope of this report, from scientific consensus, through the legality of options, Government policy to Non-Governmental Organisations (NGOs) and public opinion. As will be seen in Section 8, the gaps in information and responses to questions which are negative to a particular option form the basis of the work packages required to increase our knowledge base and, hence, the confidence with which options can be assessed.

3. There is evidence, much of which has been reviewed during the project, that a degree of scientific consensus exists on many aspects of several options, and a vast amount of work has been performed. Nevertheless, experience world-wide has proved that it is difficult to translate any apparent scientific consensus into politically deliverable action. Successful, as well as unsuccessful, programmes clearly show that the manner in which information becomes a key part of an integrated process design which involves relevant stakeholders and the public, will very significantly effect the chances of progressing any particular policy.

4. The situation in the UK is particularly difficult in that the previous experience is of a Government setting a policy of deep geological disposal, instructing the relevant body, UK Nirex Ltd (Nirex), to concentrate on a single site (which Nirex chose near Sellafield) and then, by its own procedures (the Longlands Farm Planning Enquiry), bringing down the project, and with it the policy. Whatever the scientific rights or wrongs of the Nirex decision, the background of distrust in policy and procedures provides a highly charged background to the current consultation.

5. The project team is convinced that, no matter how much information is made available, the successful implementation of a long term waste management programme cannot be envisaged without an integrated process of public and
stakeholder engagement. The perception of DEFRA and the Steering Group on the likely evolution of the process will therefore effect the actions required to provide the information needed to determine a long term waste management policy with confidence.

6. It should be noted that there are considerable generic uncertainties in the UK at present. Of the wasteforms covered by INRP, only ILW has agreed packaging, and that only for the previous policy of deep geological disposal, though Nirex contend that the current standards are robust for several options. Vitrified HLW has agreed packaging for interim storage, but no packaging or wasteform agreement exist for the ‘may be waste’ streams of plutonium, uranium and spent fuel.

7. There has been an absence of policy development since the 1997 Longlands Farm decision, which has led to subsequent activities being carried out against a background of policy uncertainty.

8. The process in the UK is now back to basic consideration of options, and this entails the consideration of some 14 major waste management options for five waste or potential waste types. The INRP has of necessity adopted a generic approach to the discussion of options. This is underlined by the fact that, with no siting contemplated for some time, INRP must deal solely with option-specific uncertainties of science, process, stakeholder and public consensus, rather than with site specific issues. These will inevitably remain areas of uncertainty at this stage and will be identified as such in the discussion.

9. Another simplification was that INRP considered the waste options in isolation rather than in combination. Thus the project has commented where individual options cannot deal with all potential waste types, but has not sought to examine the combinations which might then become necessary. This was judged to be impractical with the range of options and waste considered and the time and resources available.

1.4 General Report Structure

1. Section 2 of this report provides the context for long term radioactive waste management by reviewing the properties of UK radioactive waste, the UK radioactive waste inventory, and the risks posed by radiation. Section 3 then describes the 14 options selected for study, giving a general overview of each option and highlighting key points to feed into the evaluation of information needs.

2. Section 4 of the report broadly examines the interaction of radioactive waste policy with other areas of Government policy, environmental principles and societal concerns. Section 5 reviews legal aspects, including national legislation, international treaties and obligations. Generic scientific and technical aspects are reviewed in Section 6, with public acceptability and perspectives of environmental interest groups examined in Sections 7 and 8.

3. Having reviewed the principal areas relevant to radioactive waste management policy making, and having defined the options to be considered, Section 9 of the report, uses an analysis of work packages to define the information needs and related
activities for each of the 14 options. In Section 10 a process is suggested for taking forward the MRWS process with a manageable overall programme.

4. Section 11 comments on a DEFRA digest of the MRWS consultation responses, project conclusions are given in Section 12, and the structure and content of the project bibliography database is given in Section 14.

1.5 Relevance of Earlier HLW and Spent Fuel R&D Strategy

1. The amount of effort needed to properly evaluate each option will vary greatly depending on the maturity of its generic information and the complexity of site- or waste-specific studies required. ‘An R&D Strategy for the Disposal of High-Level Radioactive Waste and Spent Nuclear Fuel’

6, a report which resulted from a project run by the Department of the Environment, Transport and the Regions (DETR) between 1997 and 1999, offers a well thought out research plan for the geological disposal of spent fuel and HLW, and considered the impact of plutonium, uranium and ILW but only for a single management option. This may be compared with the present which is studying 14 options and five wasteforms, so the opportunity has been explored to use the HLW and Spent Fuel project as a template and to gauge the scale of the current work. It should be emphasised that though INRP used this project (which concentrates on geological disposal) as a framework, the research team considered all 14 waste management options equally within its methodology.

2. The structure of the HLW and Spent Fuel project is summed up in the figure below:

<table>
<thead>
<tr>
<th>13 Tasks – e.g. Waste Arisings, Reference Disposal Concept</th>
<th>P3, Main Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 Principal Activities – e.g. Define disposal and safety concept, decide retrievability policy</td>
<td>P24, Outline Rep. Dev Plan</td>
</tr>
<tr>
<td>47 Policy and Technical milestones – e.g. Initiate consultation process, initiate site selection process, adopt the site</td>
<td>P3, Draft Research Requirements</td>
</tr>
<tr>
<td>193 R+D Questions - e.g. How can relevant stakeholder groups be identified comprehensively, What is the maximum spent fuel packing density in the canister to avoid criticality, What are the repository design options to facilitate retrievability</td>
<td>P24, Main Report</td>
</tr>
<tr>
<td>60 Research Topics (RT) – e.g. risk and safety communication, HLW Canister Desi</td>
<td>P20, Main Report</td>
</tr>
<tr>
<td>60 Research Topic (RT) Definitions – description, questions addressed, study type, category, commentary etc</td>
<td>P28 et seq Draft Research Requirements</td>
</tr>
</tbody>
</table>

3. The 60 research topics were programmed over a 40 year period, to meet the policy and technical milestones, and each research topic was defined as a work package. A

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*507*
A typical example is given below. As can be seen, the outline description gives, in effect, the key questions which must be answered by the work package, together with the form of the study (i.e. from desk study on one hand to site-specific field work on the other). The approximate duration of the package is shown, together with where it fits in the notional 40-year programme devised by the study.

<table>
<thead>
<tr>
<th>Phase Generic</th>
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<tbody>
<tr>
<td>Number</td>
</tr>
<tr>
<td>49</td>
</tr>
</tbody>
</table>

### Outline Description

The site selection process and early decisions on the disposal concept (after work on Topic 4) will have wide impacts on the content of the R&D programme underlying the RDP and there will be feedback to the siting methodology itself. Depending on the approach taken, a number of questions will need to be addressed, including:

- the impact of using deep boreholes on the range and nature of suitable geological environments assumed in the programme
- the effect of limiting the range of geological environments studied on the data gathering approach, which may differ between environments
- data availability for offshore sites accessed from land
- ability to obtain requisite data in different environments (complexity issue)
- distinguishing between similar sites.

### Questions Addressed

**POLICY, SITE SELECTION - 1 and 3-6**

<table>
<thead>
<tr>
<th>Study Type</th>
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<tr>
<td>Desk</td>
<td>1-5</td>
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<tr>
<td>Lab and/or Eng</td>
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<tr>
<td>Site specific field</td>
<td>X</td>
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<tr>
<td>X</td>
<td>5-20 Whole Prog</td>
</tr>
</tbody>
</table>

**When**

In support of Activity 18

**Who**

Implementor

**International Collaboration**

No

**Category**

| A PA/SA Related | 1 Essential |
| B Design related | 2 Desirable |
| C Communication Related | 3 Supporting |
| D Siting Related |             |

4. The project then linked each work package to the overall programmes and milestones, and also assessed the number of the packages which were appropriate for international collaboration. The assessment was that some 74% of the packages were
appropriate for such involvement. In view of the concentration world-wide on the
geological disposal option this must represent the high water mark for the potential of
international involvement, with lower potential for less popular options.

5. As mentioned above, the size and level of definition of this project allowed a
scaling exercise to be attempted for the current project. The final assessment of
possible programmes attempts to indicate how progressing a large range of options
will expand the R+D activities from the base defined by the HLW and Spent Fuel
project, and the methodology for this is introduced in Section 8 and expanded in
Appendix 8.

1.6 Evolving Project Methodology

1. The Project Plan (Appendix 1) shows a separation of ‘horizontal’ and ‘vertical’
work packages. It also, however, shows an ongoing review of literature lasting into
the final stages of the project. In the event, the sheer scale of information to be
evaluated and the short duration of the core of the project (effectively 6 months), led
to overlap between the ‘horizontal’ and ‘vertical’ phases and required the introduction
of an iterative approach.

2. Information gathering has included a literature review. This led to the
development of the INRP Nuclear Waste Management Database, which has been
included as a deliverable to DEFRA under the project scope. For completeness, a
Word version of this database is provided as Section 14.

3. The early information gathering enabled a set of generic questions to be assembled
which were peer reviewed by the Steering Group. The questions were developed over
the course of the project, and while clearly not exhaustive, were chosen to include,
either directly or indirectly, all the criteria suggested by the Radioactive Waste
Management Advisory Committee (RWMAC) in their recent review7.

4. For timescale reasons, it was decided to start using these questions in evaluating
options and defining information needs before the horizontal work packages were
complete. Subsequent developments in the horizontal packages were accommodated
by an iterative process whereby key points from option and functional analysis could
be fed into the analysis in subsequent stages. This process is detailed in Section 8 and
Appendix 8.

5. As part of the evolving project methodology the project team took advantage of
expert opinion. The Steering Committee and DEFRA officials have provided a very
significant peer review function. The authors have received expert advice and
information from Nirex, and have utilised both data and process expertise gained
through individual participation in the BNFL National Stakeholder Dialogue.
Additionally, significant technical expertise was added by Dr Charles McCombie of
the Swiss radioactive waste authority NAGRA and the Association for Regional and
International Underground Storage (ARIUS), who has a pre-eminent experience in
radioactive waste management worldwide. Professor Neil Chapman also improved

Document.”
the team’s understanding of the HLW and Spent Fuel Report. The team also consulted Dr Patrick Green (independent environmental advisor), Fred Barker (nuclear policy analyst), and had the benefit of discussions with Dr Jane Hunt of Centre for the Study of Environmental Change (CSEC), Lancaster University.
1.7 Generic Questions

1. The generic questions described above were couched such that they require yes/no answers. If all the questions can be answered in a way favourable to an option, then that option could, by definition, be pursued ‘with confidence’. In practice, many of the questions may never be capable of an unequivocal answer. Thus the degree to which the questions can be answered definitively is linked to the level of ‘confidence’ with which an option can be pursued. Any question which does not currently result in an answer supportive of the option implies that work needs to be carried out. The assemblage of these elements of work will begin to define information needs work packages that need to be completed to allow the option to go forward. These work packages are derived by a methodology detailed in Section 8 and Appendix 8.

2. At any stage in a process as complex as that to decide a radioactive waste strategy, there will be at least some opposition to any option. The decision on whether the Government of the day is confident to proceed will ultimately be a political one. This will be driven by the political perception of the implications of proceeding with the policy which will be influenced by the level of confidence indicated by the answers to the questions, and hence by the degree of completion of the information needs work packages.

3. The questions used are reproduced below. They are listed under the headings of the horizontal work packages, but it is again emphasised that additional key points from these packages, as completed, are introduced later (see Sections 8 and 9).

4. The relative importance of the questions, and hence of the work packages, will vary greatly for different options, and while not seeking to narrow down alternatives, there are many options which naturally focus on a few crucial questions and work packages which could rule that option in or out. A tabular form clarifies these issues and presented and discussed in Section 9 and Appendix 17.

5. Questions on cost and socio-economic effects have been placed in the ‘Principles and Government Policy’ section. This is probably satisfactory as the bulk of the financial liabilities fall to the Government and this has led to the announcement of the formation of a Liabilities Management Authority8 (LMA).

6. The order in which the questions are listed is not significant. The importance of the various questions will vary from option to option and depending on the values and viewpoint of the reader. In the initial presentation of options in Section 3, and in their further discussion of options in Section 8, an attempt has been made to bring out what the research team believes are the key factors to be clarified for every option.

7. The section on Environmental Interest Group Perspectives was initially merged with the Public Acceptability section [Section 7] after the derivation of the generic questions. The key points from environmental interest group perspectives are included as a separate infeed to work package definition and evaluation as shown in Sections 9 and 10 and Appendix 14. It is notable (and supportive of the analysis) that

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there is a high degree of convergence between Public Acceptability and Environmental Interest Group key points.

**1.7.1 Laws, Treaties and Obligations**

1a. Does the option involve/require international agreement?
1b. Is the option covered and permitted/prohibited by national or international laws, treaties or obligations?
1c. If the option is permitted, or at least not prohibited, would the activation of the option raise international concerns?
1d. If the option is prohibited by international treaty, is it feasible to contemplate renegotiation?

**1.7.2 Principles and Government Policy**

2a. Does the option rely on institutional survival?
   2b. If ‘yes’ are the consequences of the potential breakdown of institutional control tolerable?
2c. Does the option align with Sustainable Development (including inter-generational equity) as interpreted by Government policy?
2d. Does the option conflict with other public policy or social science considerations?
2e. Does the option violate current planning guidance?
2f. Is the option aligned with current safety and environmental regulatory guidance and principles?
2g. Is the predicted safety or environmental detriment in line with regulatory standards?
2h. Does the option lead to significant socio-economic benefits for any area chosen?
2i. Does the option lead to significant socio-economic detriment for any area chosen?
2j. Is there a Cost Benefit Analysis (CBA) threshold above which waste options would not be considered?
2k. Is the cost likely to be a determinant?
2l. Is the option affordable, notably over time?
2m. Is the timing of the option a determining factor – e.g by allowing heat generation to decay before activating the chosen option?
2n. Is enabling legislation required to allow activation of the option?
2p. Are the principles of proximity and self-sufficiency satisfied by the option?
2q. Does the option keep other options open?
2r. Is current waste policy and practice precluding or reducing the scope for selection of this option?

**1.7.3 Scientific and Technical Aspects**

3a. Is the option purely for storage with no ultimate disposal?
3b. Does the safety case of the option rely primarily on containment of radioactivity?
3c. Is the option vulnerable to natural disasters?
3d. Does the option raise serious security concerns?
3e. Does the option offer significant security advantages?
3f. Does the option crucially depend on future technological innovation?
3g. Does the option allow long term monitoring?
3h. Does the option allow the long term retrievability of the waste?
3i. Has the wasteform been decided/specified?
3j. Have types of packaging been decided?
3k. Are the processes involved in generating the safety case for the option adequately identified, and can they be transparently and credibly modelled to demonstrate safety?
3l. Can the dose to the public and environmental effects be adequately modelled and predicted?
3m. Is the dose/risk relationship adequately accepted?
3n. Does the predicted safety or environmental detriment conform to best scientific guidance for tolerability?
3p. Can the option be safely implemented in practice?
3q. Does the option apply to all wastes?
3r. Are there examples in other countries or natural analogues that can increase assurance?
3s. Does the option involve international transport?
3t. Does the option involve transport to a centralised UK site or sites?

1.7.4 Public Acceptability

4a. Is the risk analysis believable and acceptable?
4b. Is the implementation of the option part of a process which allows adequate public participation and stakeholder input to shape the process?
4c. Is the process for choosing between different siting options transparent and designed to address both national and local concerns?
4d. Is the implementation of the option part of a package which adequately values the contribution of the chosen locality in solving a national problem?
4e. Are the environmental effects deemed to be morally and ethically acceptable?
4f. Are the costs associated with implementing the option sustainable in the light of other competing social and environmental needs?
4g. Ultimately, is the consensus (however defined) adequate to enable the policy to be pursued with confidence?
2. What is Radioactive Waste?

2.1 Radioactivity and Risk

1. Radioactivity is the spontaneous disintegration of radionuclides (unstable atomic nuclei, both natural and man made) in a process known as radioactive decay. During radioactive decay energetic particles and electromagnetic radiation are emitted which are termed ionising radiation. As a result of radioactive decay, a radionuclide is transformed into another type of atomic nucleus. The rate at which this occurs is known as the activity and is measured in Becquerels, one Becquerel being one transformation per second. As time passes the activity decreases. The half-life is the time taken for half of any given amount of radionuclide to decay. For every radioactive nuclide, the half-life is unique and unchangeable.

2. Half-lives vary from fractions of a second to billions of years. After ten half lives an isotope will have diminished by a factor of one thousand. Some of the radionuclides which need to be managed in the UK have half-lives in excess of hundreds of thousands of years.

3. As its name implies, ionising radiation causes ionisation in material through which it passes, and this ionisation damages the tissues\(^9\). There are three main types of radiation which have varying levels of energy and which vary in their ability to penetrate matter. It is this varying deposition of energy within the body that relates to the amount of biological harm caused. Alpha particles consist of two protons and two neutrons, they do not penetrate far into tissue but carry large amounts of energy. Beta particles are electrons, which are not so massive and may penetrate a centimetre or so of tissue. Gamma rays are electromagnetic radiation (like X-rays and light) and are very penetrating. All three radiation types, if absorbed by tissue, cause varying levels of damage. Radiation can be absorbed directly from outside the body, or the radionuclides can be inhaled, or ingested with food. This means that even radiation which is not very penetrating can be present in parts of the body where it can cause damage.

4. The amount of damage caused is termed the dose which is measured in Sieverts (Sv). The amount of energy absorbed, and hence the dose, from each Becquerel of radiation depends on the type and energy of the radiation given out, and one Becquerel of different substances can give doses differing by a million or more. High doses of radiation cause illness (‘radiation sickness’) and can kill. At lower levels there are no prompt symptoms, but the radiation increases the risk of later disease (principally cancers) or hereditary defects.

5. The increases in risk of disease and hereditary defects have been estimated by epidemiological studies on the survivors of the Japanese atomic bomb explosions and some other groups. The risk increases seen in these groups which suffered high doses are used to predict the risks at lower doses by extrapolating both dose and risk back to zero. This assumes that no matter how small the dose is it will have a corresponding risk. This is termed a Linear No Threshold (LNT) assumption. The International

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Commission for Radiological Protection (ICRP) in its publication ICRP60 recommended a risk factor of 0.05 per Sievert for fatal radiation-induced cancers for radiation protection purposes. This value is appropriate for the general population, assuming a mix of ages. It also estimates a risk of genetic harm appearing at any time in all generations resulting from exposure of entire populations as 0.01 per Sievert. The two risk factors, 0.05 per Sievert for fatal radiation-induced cancers and 0.01 per Sievert for hereditary disease, are commonly added to give a total risk factor of 0.06 per Sievert.

6. Given these risk factors, the doses for various risk levels can be calculated, and limits of dose set to limit risk. These limits generally conform to the regime of Tolerability of Risk10. This states that high risks (generally greater than one in a thousand per annum for radiation workers) are intolerable, risks of less than around one in a million per annum are generally acceptable, and between these limits, risks are tolerable and should be minimised within practical limits (including affordability) – or As Low as Reasonably Achievable (ALARA)11. In dose terms one in a million per year is therefore around 0.02 millisieverts12 per annum, and for the public a dose of 1 millisievert (or about one in 20,000 per annum) is the maximum permitted. This compares, for example, with natural radiation, which in the UK is an annual average of 2.2 millisieverts for the whole population.

7. This concept, and the risk factors associated with it, are disputed from both directions. On one hand, a recent pronouncement by the French Academy of Medicine13 renewed its opposition to a proposed 20 millisievert annual occupational radiation dose limit as being too restrictive, and denounced the use of the LNT hypothesis to estimate health effects of low doses, saying that this has been disproved by numerous experimental and epidemiological data and that a ‘cut-off was more appropriate. Some authorities also argue that small amounts of radiation can actually be beneficial by activating the immune system of the body – hormesis14.

8. On the other hand, there are some who hold fundamentally different views on the risks represented by low doses of radiation. An example of these views is the UK Low Level Radiation Campaign which not only disagrees markedly (by a factor of 100 to 300) with the risk estimates given by National Radiological Protection Board (NRPB) and ICRP, but states that this is a deliberate falsification on the part of these bodies15.

9. The Minister for the Environment announced16 in 2001 the setting-up of a working group under the auspices of Committee on Medical Aspects of Radiation in the Environment (COMARE) to consider risk models for radiation and health that apply to exposure from internal radionuclides. A clear UK view will surely be a necessary precursor to proceeding with practical action on a chosen radioactive waste strategy.

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10 See, for example, ‘Reducing Risks, Protecting People, Health and Safety Executive, 2001.
11 For an explanation of ALARA and other terms, see Glossary and Section 5.
12 1 millisievert is a thousandth of a Sievert
13 As reported in Nucleonics Weeks, 13 December 2001.
15 See ‘The Low Level Radiation Campaign’ at http://www.llrc.org/
This subject is reviewed in more detail in Appendix 5, and the necessary policy action needs to be programmed into the overall radioactive waste process.

2.2 Radioactive Waste Toxicity and Lifetimes

1. A useful way of representing the hazard posed by radioactive waste is its Toxic Potential. ICRP 94 gives recommended figures\(^{17}\) for the dose which would result from the ingestion of each radionuclide in an amount of radioactive waste. The method then considers that the waste is dissolved in water. It then calculates how much water would be needed to dilute the waste to such an extent that someone could use the water for all their liquid intake in a year without exceeding the maximum permitted public dose of 1 millisievert. This is termed the *Ingested Toxic Potential* of the waste.

2. This method only represents the *potential* toxicity of the waste, as the waste will often not actually be soluble even if it were to come into contact with water. It does however, at least gives a relative guide to the amount of effort and analysis we should expend to make sure that the *potential* hazard does not become a reality.

3. As the radioactivity in waste decays, so the toxic potential will, in general, reduce. This has led to the use of *Integrated Toxic Potential*, which adds up the toxic potential over time, as the unit by which different types of radioactive waste could be compared.

4. A graph of toxicity against time for one tonne of a typical Pressurised Water Reactor (PWR) Spent Fuel is given below, together with the toxicity of the different waste and product streams, the products (reprocessed uranium and plutonium) which might be declared as waste, plus the toxicity of the depleted uranium associated with the manufacture of the fuel. This shows the following key points, which will be further explained later:

   a. The HLW is the most toxic waste stream for the first few tens of years.
   b. The separated plutonium then becomes the most toxic stream until about 200,000 years, when the tails uranium becomes the most toxic stream.
   c. By around a million years, the total toxicity of wastes and products is the same as the total toxicity of the uranium ore from which the fuel was made.
   d. Over that million years the total radiotoxicity of the waste and product streams reduces by a factor of about 1000.

\(^{17}\)ICRP(1994) ICRP Publication 68, Dose Coefficients for Intakes of Radionuclides by Workers – replacement of ICRP Publication 61, Annals of the ICRP, UK.
Total Instantaneous Radiotoxicity

5. The length of time a waste needs to be contained therefore varies depending on the radionuclides present, and can be very different for different wastes, for example:

- Vitrified HLW is high in fission products\(^\text{18}\) but low in plutonium. Fission products decay with a wide range of half lives, but as can be seen from the figure, their radiotoxicity reduces by a factor of around 40 between 10 and 1000 years, but takes almost 100,000 years to reduce by another factor of 40.
- Plutonium, if declared a waste, decays with an effective half life around 24,000 years, and so is reduced by a factor of 1000 in 240,000 years.
- Reprocessed uranium, and depleted uranium, if declared as waste, are predominantly U\(^{238}\). This has a half life of 4.51 billion years, and is of low activity. Uranium in nature has daughter products from uranium decay (isotopes of thorium, protactinium etc), and these, rather than radiation from the uranium itself, provide most of the dose delivered by natural uranium. These decay products are removed, initially overseas during the refining of the ore. They begin to grow in again when there are delays between subsequent stages of transport, fuel fabrication and enrichment. As this ‘grow-in’ occurs, so the radiotoxicity of both reprocessed and depleted uranium initially increases with time.
- Much of the UK ILW is from the Magnox programme, and this is mainly the magnesium alloy cans stripped from the fuel elements. As well as some fission products it also contains fragments of fuel, and therefore has some of the characteristics of HLW, plutonium and uranium as described above.

\(^{18}\) Nuclides or radionuclides produced as a result of nuclear fission where a nucleus splits and energy is released.
6. The characteristics and typical wastes in the various categories are described in more detail in succeeding sections.

2.3 Radioactive Waste and Potential Waste Inventory

1. Material for which there is no longer a use, and which is contaminated by, or incorporates, radioactivity above threshold levels defined in legislation, is known as radioactive waste. The UK regularly publishes a Radioactive Waste Inventory\(^5\), which shows the latest record of information on the sources, quantities and properties of civil and military radioactive wastes in the UK. Copies of the 1998 Inventory and a summary booklet are available from Nirex or DEFRA. An update of the Inventory for 2001 should be available in the autumn of 2002.

2. This inventory includes those materials currently considered as waste by UK policy, but does not include the materials which could become waste in future, and which are consulted upon in MRWS. These are plutonium and uranium from reprocessing, depleted uranium from uranium enrichment, and spent fuel – predominantly AGR and PWR fuel, but with some points of view seeking to include Magnox.

2.3.1 Spent Fuel

![Total Instantaneous Radiotoxicity](image)

1. Spent fuel comes from power reactors and to a lesser extent from research/prototype reactors. The latest UK Radioactive Waste Inventory (1998) contains details of four fuels from the latter category of reactors.

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\(^5\) The latest version is “Radioactive Wastes in the UK” DETR and Nirex (July 1998)
2. The current situation in the UK is that spent power reactor fuel is not considered a waste. MRWS specifically consults on whether this should continue. In the event of spent power reactor fuel being declared a waste, its heat output would lead it to be classified as HLW. For Magnox, the currently declared situation is that all Magnox fuel will be reprocessed by 2012\textsuperscript{19}. Any abrupt curtailment of reprocessing of Magnox would leave Magnox fuel to be stored. The BNFL National Stakeholder Dialogue examined such a scenario\textsuperscript{20}, and noted that cessation of all reprocessing by the end of 1999 would leave 6,600 te of Magnox fuel unprocessed.

3. A total of some 4,760 teU of AGR fuel is contracted to be reprocessed. If the AGR reactors run to currently expected lifetimes, this leaves around 2,900 teU currently uncovered by firm reprocessing contracts. Additionally, the PWR reactor, Sizewell B, will generate some 1,050 teU of fuel over its lifetime which is currently to be wet stored on site. The AGR amounts will vary if there is any change in the amount reprocessed, and the case examined by the BNFL Stakeholder Dialogue showed that cessation of reprocessing at the end of 1999 would add 4,500 teU to the AGR fuel not reprocessed.

2.3.2 Plutonium

1. Plutonium (Pu) is a radioactive element which occurs only in tiny quantities in nature. Virtually all of the plutonium which presently exists in the world has been produced artificially by reactions which occur in conventional uranium based fuels used in nuclear reactors.

2. These reactions produce a number of different ‘isotopes’ of plutonium. The principal isotopes in spent fuel from nuclear reactors are Pu-238, Pu-239, Pu-240, Pu-241 and Pu-242. Trace quantities of Pu-236 are also present, and these may be of

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\textsuperscript{19} reference BNFL press release
some significance in radiation dose rate calculations. Like U-235, plutonium is fissile (i.e. it can support an energy-producing ‘chain reaction’) and can therefore be used as either a nuclear fuel or as a material for nuclear weapons manufacture. All plutonium isotopes are fissile in the fast neutron fluxes of fast reactors or nuclear weapons. However, only Pu-239 and 241 are fissile in the thermal neutron fluxes of conventional water-cooled or gas-cooled nuclear power reactors.

3. Currently plutonium is not considered a waste in the UK, but MRWS specifically consults on whether some plutonium should be classified as waste. MRWS also quotes from the House of Lords Select Committee on Science and Technology\textsuperscript{21}, the Royal Society report ‘Management of Separated Plutonium’ and the House of Commons Trade and Industry Select Committee\textsuperscript{22}, whose pronouncements reflect a hardening of opinion against indefinite storage of plutonium and a movement towards considering some of it at least as a waste.

4. As has already been noted in Section 2.2, plutonium represents a high percentage of the radiotoxicity of spent fuel, and declaring some or all of it as a waste would have significant effect on the criticality considerations of many options, together with issues relating to containment in both disposal and storage options.

2.3.3 Natural, Depleted and Reprocessed Uranium

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Instantaneous_Radiotoxicity_due_to_Uranium}
\caption{Instantaneous Radiotoxicity due to Uranium}
\end{figure}

1. Natural uranium, as mined, contains 99.27% U\textsubscript{238} (half life 4.51 billion years), 0.72% U\textsubscript{235} (713 million years half life) and 0.006% U\textsubscript{234} (half life 247,000 years).

\textsuperscript{21} House of Lords Session 1998-9 Third Report of the Select Committee on Science and Technology “Management of Nuclear Waste” (March 1999)
\textsuperscript{22} House of Commons Trade and Industry Select Committee report on proposed BNFL Public-Private-Partnership (May 2000)
2. The uranium remaining in the spent fuel is separated out during reprocessing as uranium trioxide (UO₃), a powder. The amount of the fissile isotope, U₂³⁵, remaining varies with fuel type, from around 0.4% for Magnox, to around 0.9% for typical AGR and LWR fuels. Reprocessed uranium contains more U₂³⁴ than natural uranium and also contains small amounts (parts per million) of U₂³², which can be radiologically significant.

3. This uranium can be re-enriched and used for new fuel, and some 10,000 teU of Magnox uranium was recycled into AGR reactors in the 1970’s and 80’s. The economics of this operation depends on the processing cost of the reprocessed uranium and the price of natural uranium. At current uranium prices recycle is not economic, and the material, which is chemically inert, is being stored in drums by BNFL. If no recycle takes place, the Magnox stations run to their announced lives and THORP finishes existing UK contracts, then the amount of UO₃ stored in the UK will reach around 110,000 teU by 2012.²³

4. MRWS states that UO₃ is considered passive, but asks for comments on whether the reprocessed uranium should be considered a waste.

2.3.4 Depleted Uranium

1. Uranium is enriched in the form of uranium hexafluoride (UF₆), which is the only common uranium compound which exists as a gas at ambient temperatures. The ‘enriched’ fraction contains typically around 3-5% U₂³⁵ (compared to natural at 0.71%), while the ‘depleted’ stream generally contains around 0.2-0.3% U₂³⁵. In the UK, this ‘tails’ stream is stored in steel cylinders as uranium hexafluoride. Essentially all the U₂³⁴ goes into the enriched product, with none in the depleted stream.

2. The U₂³⁵ percentage in the ‘tails’ stream is determined by the optimisation of the cost of enrichment and that of uranium. If the price of these changes, it can become economic to refeed the depleted stream to the enrichment process to strip out more U₂³⁵ and give more enriched uranium.

3. This operation is most likely to be economic if the material is stored as uranium hexafluoride. However, UF₆ is a volatile and highly reactive substance, and MRWS asks for comments on whether depleted UF₆ should be considered as waste, and be converted to a stable form for long term storage or future disposal.

4. At present, tails uranium hexafluoride is being sent to Russia for re-enrichment. This has had the effect of reducing the UK stock. The continuation of this contract is under review, and depending on its continuation or termination, (and if no UK recycle takes place) the amount of UF₆ in storage in the UK will be between 30,000 and 50,000 teU.²⁴

²³ ‘Advice to Ministers on the Radioactive Waste Implications of Reprocessing, RWMAC, November 2000 Table 7 P27)

²⁴ But see discussion on Passive Storage in Section 2.4.
2.3.5 *High Level Waste (HLW)*

Instantaneous Radiotoxicity due to HLW & ILW

1. HLW arises from reprocessing as a liquid. The bulk of HLW is produced at Sellafield, and is programmed for vitrification into a stable glass form for storage. The amount of HLW held as a liquid is the subject of a specification agreed between the UK Nuclear Installations Inspectorate (NII) and British Nuclear Fuels plc (BNFL), and should reduce to buffer levels by 2015\(^{25}\). With the agreement of DEFRA and the Steering Group, the project team examined only Vitrified High Level Waste (VHLW) and not liquid HLW.

2.3.6 *Intermediate Level Waste (ILW)*

1. The UK defines ILW as including all waste with greater than the Low Level Waste (LLW) limits (4 GBq/te alpha or 12 GBq/te beta/gamma), but lower than the HLW limit in terms of heat generation. Thus ILW in the UK covers a multitude of waste types, activities, and half lives.

2. The programme to develop atomic weapons in the immediate post-war period led to the development of the Magnox reactor system which was subsequently used for a significant civil power generation programme. As it is based on natural uranium metal fuel capable of a limited burnup (5.5 Gwd/teU) and requiring reprocessing, the UK was at that stage committed to a significant ILW inventory. The 1998 inventory shows a total expectation of 215,000 m\(^3\) as seen in Table 1.

Table 1. Total UK ILW Arisings

<table>
<thead>
<tr>
<th></th>
<th>Operations</th>
<th>Decommissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNFL (Sellafield, Calder &amp; Chapelcross)</td>
<td>79,806</td>
<td>31,591</td>
</tr>
<tr>
<td>BNFL (Reactors sites)</td>
<td>13,490</td>
<td>28,507</td>
</tr>
<tr>
<td>BNFL (Other)</td>
<td>334</td>
<td>78</td>
</tr>
<tr>
<td>British Energy</td>
<td>7,297</td>
<td>24,088</td>
</tr>
<tr>
<td>UKAEA</td>
<td>12,621</td>
<td>8,332</td>
</tr>
<tr>
<td>Ministry of Defence</td>
<td>3,275</td>
<td>4,789</td>
</tr>
<tr>
<td>Urenco</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Nycomed Amersham</td>
<td>665</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>117,560</strong></td>
<td><strong>97,385</strong></td>
</tr>
</tbody>
</table>

3. The 45% of waste predicted from decommissioning is virtually all from plants already in existence, and is therefore committed. The Magnox programme is nearing its end, with reprocessing at Sellafield scheduled to stop by 2012 so that the ILW from both operation of the stations and from reprocessing is also largely committed. Overall only about 6% of the ILW remains uncommitted.

4. From the early 1990’s, ILW from reprocessing of both Magnox and AGR fuel at Sellafield has been promptly conditioned by encapsulation in cement in stainless steel drums. Promptly conditioned waste makes up some 12% of the currently expected UK inventory, with the rest mainly

   a. Already stored in silos, tanks or ponds on nuclear sites, or
   b. Predicted to arise from decommissioning of existing buildings, including those mentioned in (a).

5. The 88% of waste not promptly conditioned is mainly either in, or in the form of, old buildings, some dating from the 1950’s. The wastes are often poorly characterised, and many have changed condition greatly during storage. The buildings are often not up to current standards and some have been associated with problems of, for example, containment and ground contamination. This waste is clearly a primary concern, and this has been recognised in a joint study by the RWMAC and the Nuclear Safety Advisory Committee (NuSAC), which reported in Summer 2002.

6. As the figures in Table 1 illustrate, Sellafield is the predominant UK site for ILW.

7. Table 1 also illustrates that wastes from Government or Government owned organisations predominate, and some 85% of the projected inventory is currently a Government liability. This has recently been recognised by the announcement of a Liabilities Management Agency.²⁶

²⁶ See footnote 8.
"The LMA will be responsible for the Government's interest in the management of public sector civil nuclear liabilities. On behalf of the Government the LMA will take on responsibility for most of BNFL's liabilities and assets as well as those of the UK Atomic Energy Authority (UKAEA). The LMA will work in partnership with site licensees, initially the UKAEA and BNFL, and the safety, security and environment regulators to achieve the most effective and safe means of discharging the liabilities."

8. It should be noted that much of the operational waste from reactor sites and from small users is shorter lived; typically with fission products of around 30 year half lives. This means that different solutions involving decay storage may be viable for these wastes.

9. There is also a quantity of LLW which, for radiological reasons, cannot be disposed of in the LLW site at Drigg. This material has been included in the project’s deliberations, but is insignificant in both volume and activity terms in comparison with the total ILW volumes quoted above.

2.3.7. Effect of a New Programme

1. A new programme of 8 large PWR’s with spent fuel designated as waste would generate around 9-14,000 m³ of spent fuel conditioned for disposal over a 40-year life, thus more than doubling the UK’s HLW inventory. If all the spent fuel was reprocessed, the ILW inventory would only increase by about 8%, and around 90 te of plutonium would be separated. The VHLW inventory would rise by about 750 m³ and the uranium inventories would rise by about 9,000 teRU and 90,000 teDU. In terms of material currently declared as waste, the overview is that a new programme would significantly change the VHLW and/or the spent fuel inventory of the UK, while the ILW and LLW inventory remains comparatively insensitive to any new programmes even when decommissioning wastes are included.

2.4 Hazard, Risk and Uncertainty

1. The hazard presented by radioactive waste arises from the dose that it could give to humans or other organisms if the radionuclides were released and entered the biosphere. Thus the crucial factors in defining the hazards and risks represented by nuclear waste are:

   1. The safety and security of waste during storage.
   2. In the longer term the likelihood and extent of radionuclides from the waste being released into the environment and their migration within it – estimated over a time period of hundreds of thousands of years.

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27 Scenario 6 from ‘Rethinking Disposal’, RWMAC, January 1998 with conditioned spent fuel volumes of 0.9-1.5 m³/teHM, and VHLW volumes of 0.08 m³/teHM as given in ‘Advice to Ministers on Radioactive Waste Implications of Reprocessing’, RWMAC, November 2000, p25.
3. The relationship between these possible releases of the material and dose – over the same time periods.
4. The relationship between dose and risk.

2. While in storage the safety of the waste is regulated to risk-based standards by the NII. The regulatory framework aims to ensure that an accidental release of the waste does not occur. The project team assumed that the adequacy or otherwise of this regulatory regime was not part of its remit.

3. Some of the waste in store is in the form of liquid high level waste, other liquids, sludges and particulates which are potentially mobile. If a release of such wastes did occur the potential consequences for the environment and for human health could be significant. These potential consequences are much reduced if the waste is conditioned into an inert solid form which is then stored in modern purpose-built facilities. This is termed ‘passive storage’. The NII has produced guidance to its inspectors on the attributes of passive storage systems, which have been agreed by the operators.

4. Neither ‘passivity’ nor ‘passive storage’ are absolute terms, but describe the conditioning and packaging of waste into a solid form which can be stored without significant risk of releasing radioactive material in the short and medium term. It is probably more correct to describe the concept as providing a waste and storage system which is sufficiently passive to ensure the containment of the waste for the timescale being contemplated.

‘All existing waste and waste arisings must be packaged in safe, monitorable and retrievable interim storage in the shortest possible time.

Interim storage offers an acceptable solution for 50/100 years but research must continue into long term storage and the possibility of disposal.’

5. Existing Government Policy, as articulated in Cm2919 (1995)\textsuperscript{30}, contains a presumption that conditioned waste will generally be suitable for deep geological disposal. This is ensured by a ‘letter of comfort’ provided by Nirex to operators producing wastes for storage. Without a ‘letter of comfort’ the NII will not license any waste producing process. Cm2919 did state (para 113) that ‘where early treatment of waste will secure worthwhile safety benefits, or worthwhile economic benefits without prejudicing safety, the general presumption against action which might foreclose future waste management options may be relaxed’, but this has never extended to treatment without a Letter of Comfort, though, as previously mentioned, some stable solid waste is stored unconditioned. It is therefore the case that all treated ILW in the UK is considered by Nirex as broadly suitable for deep geological disposal as envisaged before 1997.

\textsuperscript{29} Interim Report of the Waste Working Group in the BNFL National Dialogue, 28 February 2000. Interim reports can be found at www.the-environment-council.org.uk
\textsuperscript{30} Cm 2919, Review of Waste Management Policy, Final Conclusions, HMSO, London, July 1995
6. The timescale for storage has been examined by the NII, and the following guidance is given to inspectors\textsuperscript{31}.

‘NII proposes that, for radioactive waste and material being placed in storage now, an overall period of containment of at least 150 years should be assumed. This is comprised of the following consecutive periods:

- a period of interim storage of at least 50 years prior to the availability of a disposal facility;
- a period of about 50 years during which the facility is operational and the wastes are emplaced; and
- a further period of at least 50 years during which the facility remains open and waste packages can be retrieved if required.’

7. This is not to be taken as implying that Government has accepted disposal as the chosen long-term management option, but should be seen more as a cautious planning assumption made by the NII.

8. There is therefore a need to ascertain whether this timeframe for interim storage is an acceptable background to the process of choosing ‘practical management options for solid long-lived radioactive wastes’\textsuperscript{32}. In particular:

- Is an emphasis on moving as soon as is reasonably possible to passive, safe, monitorable and retrievable interim storage a suitable policy for untreated waste?
- Is an overall period of interim storage of 100 - 150 years a suitable planning basis for radioactive waste and material being placed in storage now?
- Should the preserving the possibility of eventual deep geological disposal still effectively define the specification for ILW to be treated for storage or could a more general specification covering a number of options be found?

9. These questions need to be answered well in advance of the policy envisaged by MRWS being defined, and represent an urgent area for policy decision. They are included in the generic option questions by the inclusion of “is current waste policy and practice precluding or reducing the scope for selection of this option?” and “Does the option keep other options open?”

10. Any long term waste management option chosen will have a possibility of releases of radioactive material to the environment. The ability to model the magnitude and timescale of such releases will be central to the long term safety assessment of the option. This modelling must assess the effects of natural processes (weathering, climate change etc) as well as such human factors as loss of institutional control and intrusion. As previously mentioned, the long half lives of some of the radionuclides involved will require such predictions to cover hundreds of thousands of years. The generic safety questions for any option are whether the modelling of outcomes over long periods is adequate to give confidence in the safety of the option, and whether the option can be safely implemented in practice.

\textsuperscript{31} Guidance for Inspectors on the Management of Radioactive Materials and Radioactive Waste on Nuclear Licensed Sites, 13 March 2001

\textsuperscript{32} Information Needs Research Project, agreed project scope, DEFRA, 2001
11. These generic questions will be dealt with in considerably more detail for the individual options.

12. If it were for the moment assumed that the releases of radioactive material to the environment, and the consequent doses to humans could be adequately modelled, then the safety aspects of the acceptability of a particular option depend on the risk involved and its acceptability. This has several facets:

a. Does the dose to humans sufficiently define the safety of a particular option? The principles of radiological safety as put forward by ICRP have stated that protection of the human at the individual level is sufficient to ensure protection for the environment (i.e. other biota). This has been questioned recently and work is proceeding in both the EC and the OSPAR\textsuperscript{33} to test the ICRP statement. ICRP are awaiting the outcome of such studies and have indicated that they will revisit their advice.

b. Is the dose/risk relationship adequately defined? As discussed in Section 2.1 and Appendix 5, the ICRP/NRPB values underpin radiological risk calculation and regulation both in the UK and world wide, but as has been mentioned opinions vary on both sides. The disposal of radioactive waste has been aimed at a peak risk to a maximally affected group of one in a million per annum\textsuperscript{34}. As discussed this risk level can be related to a dose of around 0.02 millisieverts per annum. A material increase in the assessed risk per unit dose would have a significant effect on the standards assessed for future waste options.

c. What risk is acceptable and to whom? The regulation of nuclear operations by the NII is based on the concept of ‘Tolerability of Risk’. As has been outlined, the whole question of the risk, and its acceptability to people and/or the environment crucially underpins the evaluation of all options. Broadly owned answers to these questions must precede real progress towards a long term waste policy. They are also the sort of questions demanding a considered process which involves all relevant stakeholders and the public.

\textsuperscript{33} Oslo and Paris (OSPAR) Commission, Contracting Parties to the 1992 Convention for the Protection of the Marine Environment of the North East Atlantic

3. Long Term Waste Management Options

3.0 Generic Considerations

3.0.1 General

1. As will be judged by the bibliography in Section 14 of this report, the last 50 years has seen a very large amount of work done on radioactive waste management options. Most possible options were defined early, and a Battelle report of 1974\textsuperscript{35} shows the state of maturity of all current concepts nearly 30 years ago. There is also no shortage of high-level reviews of the subject, many of them entailing prodigious international effort\textsuperscript{36}. There is, however, a profound difference between being able to define a concept and evaluate its strengths and weaknesses in a generic sense, and being able to satisfactorily analyse the processes involved in safety and practicality at a given site for a given waste form and inventory. One key factor in evaluating options is therefore how far they have advanced from the concept stage towards a well defined evaluation methodology which can accommodate site- or waste inventory-specific data and end up with a credible safety case, project plan and cost estimate which will withstand determined peer review and adversarial pressure.

2. The amount of work which has been performed and progress which has been made on the various options will be seen to bear little relation to their potential for being the best practical environmental option. For example, a great deal of scientific opinion attests that sub-seabed options offer a far more robust safety regime than any land-based option – yet political and to a great extent public opinion will be seen to offer a formidable barrier to progress in this area. The present study can only attempt to point out the broad areas which would have to be studied to an acceptable level and the legal and political barriers which would need to be overcome to make such study worthwhile. 50 years of experience has proved the pursuit of ‘the best’ in the long term management of radioactive waste to be an illusory concept. The UK is currently engaged in a process, the success of which would be the identification of ‘the acceptable’, at a level of consensus which would allow the Government to proceed ‘with confidence’ within a few years.

3.0.2 UK Considerations

1. During the consideration of waste management options, it is necessary to bear in mind that different methods may be suitable for different waste streams. The possible differences in treatment for long- and short-lived wastes have already been mentioned, and waste classification is specifically consulted on in MRWS, but topics such as whether to co-dispose of ILW and HLW underlay all option considerations. In theory this could lead to a multiplicity of options for different wastes in different places – particularly if the proximity principle (see Section 5) is taken to its logical conclusion. This aspect is best addressed after analysing all the individual options, and is dealt with in Section 9 of the report.

\textsuperscript{35} High Level Radioactive Waste Management Alternatives, BNWL-1900, 1974

\textsuperscript{36} See for example references 006, 101, 109, 400, 402, 409, 459, 461, 506, 507, 508, 520, 529, 552, 585.
2. The 28 November 2001 Parliamentary announcement of an LMA brings the prospect of co-ordinated management of £48B of the currently assessed UK waste liabilities\(^{37}\), including some 85\% of the UK’s ILW. The form of the new body has been proposed in a White Paper\(^ {38}\) for consultation in 2002, with the basic format being discussed in the UKAEA Quinquennial Review (QQR) paper of November 2001\(^ {39}\). This makes a lucid case for a Non Departmental Statutory Body (NDSB) directly accountable to Ministers and to Parliament. This will facilitate the national co-ordination of the waste management programme and could offer both economies of scale and a strong and credible stakeholder forum for process of defining waste policy.

3.0.3 Transport

1. Transport is an element in all options, and its consideration needs to span the whole range of topics from policy and legal, through technical and safety, to public acceptability. The two main categories of transport, national and international, are considered here.

3.0.3.1 Transport within the UK

1. The transport of nuclear materials is subject to national and international regulation and standards. The safety record of nuclear materials transportation is statistically very good but historically transport has been an issue which has aroused protest and problems of public acceptability. Within the UK there are numerous local groups who lobby against movements of nuclear material, particularly through large centres of population such as London.

2. The nuclear industry would claim that the safety of transport is provided through the packaging of the materials, the containers it is transported in and safety features of the transportation itself. However, there remain areas of controversy, and work on any option must answer key questions on the transport it entails:

KT1 Safety of containers and relevance of container testing regime to actual accident conditions.
KT2 The likelihood and consequences of severe accidents.
KT3 Risk from exposure to radiation during transit and routine surface contamination of the flask or container.
KT4 Ethical and public acceptability considerations of exposing communities to perceived risks from an activity from which they receive no direct benefit.
KT5 Risk from exposure to residual contamination arising from parking or laying-by of radioactive waste containers.
KT6 Scepticism about the assurances from the industry about the inherent safety of transport

\(^{37}\) Statement on 28 November 2001 on future management of public sector civil nuclear liabilities, Hansard Column 990
\(^{38}\) DTI White Paper, ‘Managing the Nuclear Legacy’, 4 July 2002 – note that this updates the total liabilities to be assumed by the LMA to £48B
\(^{39}\) UKAEA Quinquennial Review, Report 2, DTI, November 2001
3.0.3.2 International Transport

1. The transport of nuclear materials across international boundaries presents public acceptability problems, with the activity being perceived as presenting risks which are not balanced by any direct benefit to the populations concerned. This has been particularly important in the global protests which have accompanied the sea transportation of spent nuclear fuel and the return of plutonium oxide and Mixed Oxide Fuel (MOX) fuel.

2. It must be anticipated that options involving international transport of radioactive waste will be subject to intense public scrutiny and potential protest. This will be so regardless of the categorisation of the waste transported. A large increase in the frequency of international movements could either intensify opposition or decrease it in the longer term if an accident free record was achieved.

3. Addressing the issues associated with the transport of nuclear materials involves the same processes as conducting a positive and successful consultation about waste management options. These include clarity of objective, co-operative dialogue to establish the justification of the need, transparency of operation, inclusiveness of consultation, joint-sponsorship of assessments and investigative operations, compensation packages for inconvenienced communities, openness in the execution of the task, demonstration of the effectiveness of the engagement package and scrutiny and monitorability of the results.

3.0.4 Discussion of Options

1. The purpose of option discussion in this section is to provide a definition and basic description of each option to put the succeeding sections on Law, Principles and Policy, Scientific Aspects and Public Acceptability into context. The description of each option will be completed with an initial view of the key factors to be borne in mind. They cover:

   a. Technology
   b. Cost
   c. Legal Status
   d. International Status
   e. Other key factors

2. Where options refer to ‘disposal’, there is an assumption that the waste management option has been carried out with no intention of retrieving the waste. This definition is discussed and clarified in ‘Law, Treaties and Obligations’, Section 5. All UK options would be subject to UK planning law.

3. One factor which is not used for differentiating between options is critical group dose. This is because any option which meets a specific safety case will have to satisfy the same radiation protection standards for critical group dose. The doses achieved in practice will in all cases be particular to the actual site and scheme adopted, and are not capable of being estimated at present. Thus the RWMAC
criterion\textsuperscript{40} of ‘potential health impact’, is brought into discussion here as ‘likelihood of achieving a viable safety case’.

4. The costs associated with an option will clearly be an important factor in the decision process to decide future management options for radioactive waste. The project team were not asked to deal with this issue directly, but the following review of options makes some comments on relative costs where these are known. The degree to which cost should influence decision making is the subject of a wide diversity of views, which will need to be taken account of in the ongoing policy development process.

\textsuperscript{40} see A2.13 of ref 135
3.1 Option 1. Above Ground Storage

1. In this option, the policy is for the waste to be stored indefinitely, with no plans for subsequent disposal or the substitution of any other waste management option.

2. The ILW and HLW are conditioned (where necessary) as soon as is reasonably practicable, as are the plutonium and uranium if declared waste. Any Magnox fuel is conditioned for storage as soon as is reasonably practicable. This is marked ‘Stage A’ on the diagram and puts all wasteforms into a passive enough state to plan on storage for several decades, and research and development might be able to extend this phase to ‘many decades’.

3. AGR and PWR fuels may be stored without conditioning for several decades, but plans would be required to increase the level of passivity in the longer term. As no wasteform or store will have an infinite life, a stage of conditioning (PWR and AGR fuel), reconditioning (other waste forms), and store refurbishment/replacement is shown, leading to Stage B. Subsequently stores and/or wasteforms will need attention – leading to Stages C, D and so on.

4. The need for suitable funding and technology for waste and store refurbishment extends indefinitely in this option, as does the need for institutional control of the waste and waste stores.

5. A major consideration of this option is the siting of the stores, which could range from a single centralised store, via separate stores for different waste types, to dispersed stores, possibly at current nuclear sites.
6. Key factors of this option which will be discussed in Section 8 are:

K1.1 The technology of storage is mature, though currently not optimised for indefinite storage. Wasteform lifetimes and retreatment cycles will entail significant R+D.

K1.2 The costs of the option are capable of being estimated from current knowledge. In discounted terms they may appear quite modest, whereas the indefinite nature of the activities makes overall costs unlimited in undiscounted terms.

K1.3 There are no present legal barriers to adopting this option, though it would be subject to UK planning law and could be taken to contravene principles of sustainable development.

K1.4 No other country has adopted indefinite storage as policy, though many have it as a de facto ongoing response to lack of progress on other options.

3.2 Option 2. International Above Ground Storage

1. This option is identical to Option 1 except that the long term storage takes place in another country. There is therefore a stage of international transport in this option, which is here shown taking place during Stage A, but could be delayed to later stages, for example when all wastes have been conditioned at Stage B.

2. International transport brings in different considerations, as does the siting, competence and motivation of the prospective host country, which may significantly affect views on security and safeguards.
3. The availability of geological, geographical and demographical conditions unavailable in the UK may be a factor affecting the lifetimes and security of wasteforms and stores.

4. Considerations of technology, funding and institutional care are the same as in Option 1.

5. Key factors of this option, which will be discussed in Section 9, are:

K2.1 The technology of storage is mature, though currently not optimised for indefinite storage. Wasteform lifetimes and retreatment cycles will entail significant R+D.
K2.2 The costs of the option are capable of being estimated from current knowledge. In discounted terms they may appear quite modest, whereas the indefinite nature of the activities makes overall costs unlimited in undiscounted terms.
K2.3 International Storage is not covered under international law, but import and export of radioactive waste is strictly controlled and in some cases prohibited.
K2.4 The option could be taken to contravene principles of sustainable development.
K2.5a No other country has adopted international storage as policy.
K2.5b The ethical and economic aspects of this option are significant, particularly in ensuring how the indefinite care involved would be funded and ensured.
K2.5c The option involves international transport. Apart from the associated safety and public acceptability debate, the economics will become more unfavourable for high volume waste streams such as the UK’s ILW.
3.3 Option 3. Underground Storage

1. This option is the same as Option 1 (Surface Storage) apart from the fact that the storage is underground. This may give security advantages, and safety benefits in accident situations. If the siting of the store has taken into account eventual disposal options the ability to change to a disposal regime may be relatively simple at a later stage. However, as long as the regime is for storage, the waste conditioning/reconditioning, and the store refurbishment or replacement, will need to proceed as in Options 1 and 2. The need for technology, funding and institutional care are the same as in Option 1.

2. The same siting considerations as in Option 1 (dispersed or centralised) will also apply to this option, though the considerations will be different because of the subsurface siting and any considerations of eventual disposal.

3. Key factors of this option, which will be discussed in Section 9, are:

K3.1 The components of the technology of underground storage are relatively mature, though the intention for indefinite storage will restrict the geological settings which can be considered, and the technology would require R+D to optimise it for indefinite timescales. Wasteform lifetimes and retreatment cycles will entail significant R+D.

K3.2 The costs of the option are capable of being estimated from current knowledge. In discounted terms they may appear quite modest, whereas the indefinite nature of the activities makes overall costs unlimited in undiscounted terms. If the option is to include the provision for eventual conversion to disposal, a full repository safety case will be required at an
appropriate stage, and many of the elements will need to be in place before even the storage option can be implemented.

K3.3 This option is not prohibited under UK law but its implementation would be subject to UK planning law. The option could be taken to contravene principles of sustainable development.

K3.4 No other country has adopted indefinite underground storage as a policy, though Sweden has an underground interim spent fuel store, CLAB.

K3.5 The apparent permanence of underground storage may raise more public acceptability issues than above ground storage, though on the other hand it may be presented as offering security advantages.

3.4 Option 4. International Underground Storage

1. As in the differences between Options 1 and 2, this option only differs from the preceding Option 3 (Underground Storage) because the storage site is in another country. There is therefore a stage of international transport in this option, which is here shown taking place during Stage A, but could be delayed to later stages, for example when all wastes have been conditioned at stage B.

2. International transport brings in different considerations, as does the siting, competence and motivation of the prospective host country, which may significantly affect views on security and safeguards. The availability of geological, geographical and demographical conditions unavailable in the UK may be a factor affecting store and/or wasteform lifetimes and security. This may be especially true if eventual geological disposal is considered.
3. Considerations of technology, funding and institutional care are the same as in Option 2.

4. Key factors of this option, which will be discussed in Section 9, are:

K4.1 The technology of storage is relatively mature, though the intention for indefinite storage will restrict the geological settings which can be considered, and the technology would require R+D to optimise it for indefinite timescales. Wasteform lifetimes and retreatment cycles will entail significant R+D.

K4.2 The costs of the option are capable of being estimated from current knowledge. In discounted terms they may appear quite modest, whereas the indefinite nature of the activities makes overall costs unlimited in undiscounted terms.

K4.3 International Underground Storage is not covered under international law, but import and export of radioactive waste is strictly controlled and in some cases prohibited. The option could be taken to contravene principles of sustainable development.

K4.4 No other country has adopted international storage as policy.

K4.5a The ethical and economic aspects of this option are significant, particularly in ensuring how the indefinite care involved would be funded and ensured.

K4.5b The option involves international transport. Apart from the associated safety and public acceptability debate, the economics will become more unfavourable for high volume waste streams such as the UK’s ILW.

K4.5c The apparent permanence of underground storage may raise more public acceptability issues than above ground storage, though on the other hand it may be presented as offering security advantages.
3.5 Option 5. Underground Disposal

1. Unlike the first four options examined, underground disposal assumes no intention to retrieve the waste, though this may be provided for. The objective is to place the waste (conditioned as needed) into a deep geological repository, in suitable engineering and geological conditions, so that the radioactivity in the waste will not escape at a rate or in a timescale to produce unacceptable effects to people or the environment. Once disposal has been completed, institutional control may be safely removed, though ongoing monitoring and provision for retrieval of the waste if required are features of most current programmes.

2. The ILW and HLW are conditioned (where necessary) as soon as is reasonably practicable, as are the plutonium and uranium if declared waste. Any Magnox fuel is conditioned for storage as soon as is reasonably practicable. This is marked ‘Stage A’ on the diagram and puts all wasteforms into a passive enough state to plan on storage for several decades. Research and development could extend this phase to ensure that a repository is available and disposal can take place without store and waste refurbishment.

3. AGR and PWR fuels may be stored without conditioning for several decades, but will need to be conditioned before disposal, and other wastes may need further packaging or conditioning before being emplaced in the repository.

4. Once the waste has been disposed and the repository backfilled, there is no scientific need for monitoring or provision for retrieval. From this stage the amount of societal care and financial/technological need is a function of societal uncertainty.
about the correctness of the science involved, or the need to guard against societal problems such as safeguards and security.

5. A large number of variants of geological disposal have been studied, with disposal in many different geological settings, different excavation techniques and disposal depths. Though some of the concepts have been extensively tested others are still at the conceptual stage. The different concepts entail different waste packing requirements and associated R+D.

6. Key factors of this option, which will be discussed in Section 9, are:

K5.1 The components of the technology of underground disposal are relatively mature, and the overall and site-specific aspects of R+D required have been estimated for the UK by ‘An R&D Strategy for the Disposal of High-Level Radioactive Waste and Spent Nuclear Fuel’

K5.2 The costs of the option can be estimated once the siting and engineering concepts are known, but uncertainties will exist until a full safety case analysis has been performed, and the entire project will be at risk until adequate public acceptance has been delivered.

K5.3 This option is not prohibited under UK law but its implementation would be subject to UK planning law.

K5.4 All countries which have adopted a long term radioactive waste management policy have adopted underground disposal, though in some cases combined with work on Partition and Transmutation (see option 12 below). Russia has in the past adopted underground disposal using pumped liquids (see option 7 below).

K5.5 Considerable emphasis is now being given to retrievability and monitoring, and these are significant features in current work, notably in Nirex’s Phased Disposal Concept.

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41 507
42 434
3.6 Option 6. International Underground Disposal

1. As in the differences between Options 1 and 2, (and 3 and 4), this option only differs from the preceding Option 5 (Underground Disposal) because the disposal site is in another country. There is therefore a stage of international transport in this option, which is here shown taking place during Stage A, but could be delayed to later stages, for example when all wastes have been conditioned for disposal at Stage B.

2. International transport brings in different considerations, as does the siting, competence and motivation of the prospective host country, which may significantly effect views on security and safeguards. The availability of geological, geographical and demographical conditions unavailable in the UK will be a major consideration.

3. Considerations of technology, funding and institutional care are the same as in Option 5, but the considerations of providing these in a foreign country may bring in different factors.

4. Key factors of this option, which will be discussed in Section 9, are:

K6.1 The overall R&D requirements are similar to Option 5. The components of the technology of underground disposal are relatively mature, and the consideration of international sites can allow a wider choice of favourable siting parameters.43

43 'High isolation sites for radioactive waste management', Pangea Resources Australia Pty Ltd, 1999
K6.2 The costs of the option can be estimated once the siting and engineering concepts are known, but uncertainties will exist until a full safety case analysis has been performed, and the entire project will be at risk until adequate public acceptance has been delivered.

K6.3 International disposal would require an international legal agreement and would need to comply with international conventions. Current UK policy does not allow waste to be exported.

K6.4 No country has adopted international underground disposal as a policy, though some, notably Switzerland, include it as part of a dual track policy, where national and international solutions may be looked at in parallel.

K6.5 The option involves international transport. Apart from the associated safety and public acceptability debate, the economics will become more unfavourable for high volume waste streams such as the UK’s ILW.

3.7 Option 7. Direct Injection

1. This option involves the injection of radioactive wastes in liquid form deep into geological strata using advanced engineering techniques. To date, this process is only known to have taken place in Russia where it is claimed that 46 million m³ of waste has been injected into deep geological strata or ‘reservoirs’. The option, together with a variant which pumped liquid waste and cement grout into hydraulically opened fracture planes in rocks, was also formerly practiced in the US for low level liquid waste.

2. In the Russian setting the injection sites were close to the plants producing the liquid waste. In the UK this would by no means be certain, and if the injection site
was remote the transport of large volumes of liquid waste is liable to be very problematic. In the figure the method is shown as an add-on to existing waste practices, with transport as a solid and a dissolve/slurry stage at or very near the injection site.

3. The disposal method requires long and exhaustive research into geological formations and is not seen as meeting isolation requirements. While this option is not seen by the Russians as an alternative to conditioning and solidification of liquid radioactive wastes, it is, nonetheless, an option which could be considered for certain types of waste especially those containing short-lived fission products and where favourable geological conditions can be identified.

4. Since this option involves the direct injection of liquid radioactive waste, it relies on geological barriers and lacks the engineered barriers available in solid waste disposal. The option of mixing cement with the liquid waste and injecting the resulting grout goes some way to address this. Direct injection is therefore only likely to produce long term containment in very particular and well characterised geological conditions.

6. Key factors of this option, which will be discussed in Section 9, are:

K7.1 The separate elements of the technology for this option have been developed to a mature stage, but have only brought together in the examples quoted.
K7.2 If plants and injection site could be co-located, and a viable safety case could be generated, this would be a cheap option. Neither of these attributes are likely in the short/medium term in the UK.
K7.3 The concept would not be in violation of UK legislation provided that aquifers and water supplies are adequately protected. The operator would be liable for damages in common law.
K7.4 This option has been developed to implementation stage in Russia, and to a limited extent in the US but only to concept stage elsewhere. It has the disadvantage compared to the geological disposal of solid waste of two fewer barriers to radionuclide migration.
K7.5 Even if a safety case could be made, the probable absence of co-location and the current programmes of solid waste conditioning make the application of this option difficult in the UK.
3.8 Option 8. Disposal at Sea

1. This option involves releasing packaged waste to descend to the seabed, with no intention of retrieval. It would rely for its safety case on the delay in release of activity afforded by the packaging followed by modelling of dilution and dispersal from the chosen deep ocean location, and the takeup of radioactivity into the food chain.

2. Packaged waste, conditioned to enable safe transportation, is dropped directly from a ship or aircraft into areas of the ocean where conditions including depth, physical isolation and absence of exploitable species ensure acceptable doses to populations via the food chain. This option does not include containers designed for deep penetration of the seabed, which are examined under Option 9.

3. The UK practiced disposal at sea for ILW and LLW up to 1983. Subsequently this practice was stopped by the London Dumping Convention. Early disposals were made in coastal waters, and from the mid 1970s the waste was disposed onto Atlantic abyssal plains and into deeps. The option therefore has been considered for both UK and international waters.

4. Experience from the UK sea dumping emphasises that, if prompt release of radionuclides is to be avoided, packaging must be designed to remain intact at the disposal depths envisaged.

5. Key factors of this option, which will be discussed in Section 9, are:
K8.1 The elements of the technology for the conditioning, overpacking and transporting the waste are available, though there would be waste-specific and site-specific elements to be investigated.

K8.2 The cost of the option should be low, unless stringent conditioning and packaging requirements are identified.

K8.3 This option is currently specifically excluded by international agreement.

K8.4 No reference has been found to the option being examined for other than low and intermediate level wastes.

3.9 Option 9. Sub-Seabed Disposal

1. This option has two sub-categories:

   a. free fall disposal” using weighted, shaped containment for deep penetration into the sea floor
   b. emplacement into pre-excavated sub-seabed repositories or boreholes.

2. Both the sub-options use the isolation created by seabed locations and the geological barrier afforded by sediments as the means by which radioactivity can be effectively isolated from the environment for thousands of years.

3. The majority of the work carried out on this option has been undertaken by the Seabed Working Group (SWG) under the auspices of the Oranisation for Economic Cooperation and Development (OECD). The SWG concluded, after a 10 year work programme, that suitable areas of the seabed exist for this method to be seriously considered. The option could be considered for both UK and international waters.
4. Both sub-options are designed to achieve disposal, but both can offer a degree of retrievability. In the emplacement option, retrievability will be dependent on the depth of water, the borehole depth, the number and design of containers placed in each, the configuration of the boreholes themselves and the choice of backfilling technique. Free fall disposal will also offer retrievability depending on the water depth and penetration achieved.

5. Both methods of sub-seabed disposal are considered to be technically and economically viable. Modelling can indicate that only a small dose would reach the general population, with packages surviving intact and the sediment barrier containing most of the radionuclides for thousands of years. However, the adsorption properties of sediments need further examination together with the effects of penetrators on the sediments penetrated, and the role of borehole backfilling.

7. Transportation would be specialised, with ‘moon pool’ vessels for penetrometer release, semi-submersible emplacement platforms and drill ships/platforms for deep ocean drilling.

8. Key factors of this option, which will be discussed in Section 9, are:

K9.1 The elements of the technology for the conditioning, overpacking and transporting the waste are available. The drilling and emplacement techniques for the deep borehole and penetrometer techniques have been demonstrated, though deep hole closure has not. There would be many waste-specific and site-specific elements to be investigated.

K9.2 The cost of the option would depend on the technique chosen and the amount of development work required.

K9.3 This option would be dealt with under the provisions on the UN Law of the Sea Convention.

K9.4 The option was the subject of an extensive international programme under OECD auspices, but has been quiescent since 1987. There is still scientific support for this option on safety grounds.
3.10 Option 10. Disposal in Ice Sheets

1. This option would only be available outside the UK and therefore is deemed to be automatically an international option. Most studies examine disposal in Antarctic ice-sheets.

2. There are three main concepts:
   a. emplacement in boreholes with self-melting achieving descent of the waste to the bedrock.
   b. Anchored emplacement, where the depth of penetration by melting is controlled by cables from the surface, and
   c. Surface storage, where packaged waste is originally placed on legs on the surface, so that it is only incorporated into the ice sheet by snow and ice accumulation, and it does not melt down to bedrock.

3. While disposal in ice-sheets does offer some monitoring and retrieval possibilities, these are likely to decrease with time, especially for sub-option (a). Because ice-sheets are not static the option does not achieve permanent isolation. In Antarctica, the ice sheets move away from the central plateau at a rate of several metres a year and ice eventually reaches the coast where it ‘calves’ into icebergs. These melt in the warmer summer seas over a period of years. In geological time, therefore, the waste will be accessible to the marine environment.
4. Note that the first two concepts are only applicable to wastes whose heat output is large enough to achieve self-melting descent. This may rule out the bulk of the UK inventory volume as the ILW has low heat generation.

5. Key factors of this option, which will be discussed in Section 9, are:

K10.1 The elements of the technology for the conditioning, overpacking and transporting the waste are available, though there would be waste-specific and site-specific elements to be investigated. The transport to the disposal site would require development. The option has been examined only at the most generic level.

K10.2 The cost of the option would be driven by transport and overpacking costs, but would probably be within the mid-range of the options.

K10.3 Only Antarctica and Greenland are significant sites. The option is specifically excluded for Antarctica by international treaties. As a Danish dependency, the use of Greenland would have similar restrictions to option 6.

K10.4 The option is not being worked on by any other country or agency.

K10.5 The option involves international transport. Apart from the safety and public acceptability debate the economics will become more unfavourable for high volume waste streams such as the UK’s ILW.
3.11 Option 11. Disposal in Subduction Zones

1. This disposal method envisages emplacing waste in a repository in a subducting tectonic plate. The geological barriers must be sufficient to prevent the waste re-entering the biosphere before it was conveyed into the mantle by the subduction process. Once in the mantle dilution would be very large, and return times to the biosphere would run to many millions of years.

2. Subduction zones are invariably offshore, and there are none in UK coastal waters. This method is therefore by definition an international solution in UK terms and will attract the complications also attending Options 2, 4, 6, and 10 (and possibly 8 and 9).

3. The emplacement techniques envisaged vary, with deep sub-seabed boreholes and conventional tunnelling both having been considered.

4. It is also conceivable that free fall penetrometers, if designed to penetrate deeply enough into sediments within known tectonic plate activity zones, could be used as the vehicles for carrying waste into subduction areas.

5. Key factors of this option, which will be discussed in Section 9, are:

K11.1 The elements of the technology for the conditioning, overpacking and transporting the waste is available, though there would be waste- and site-specific elements to be investigated. The option has been examined only at the generic level.

K11.2 The cost of the option would be driven by emplacement with overpacking also a significant element. It would be unlikely to be significantly cheaper than
geological emplacement on land.

K11.3 This option would be dealt with under the provisions of the UN Law of the Sea Convention.
K11.4 This option has not been adopted by any other country, though there is intense international study of subduction zones for purely scientific purposes.
K11.5 The option involves international transport. Apart from the safety and public acceptability debate, the economics will become more unfavourable for high volume waste streams such as the UK’s ILW.

3.12 Option 12. Partitioning and Transmutation

![Diagram of Option 12. Partition and Transmutation]

1. Partitioning refers to separating spent nuclear fuel and other radioactive waste products into its constituent parts, and transmutation refers to changing the radioisotopic makeup of the waste fractions by bombarding them with neutrons. This is done using either conventional nuclear reactors or accelerator systems to provide the neutrons. The motivation for these activities is to reduce the radiotoxicity of the waste and its longevity, though some programmes are also motivated by higher energy yields from fissile elements in the waste. Note that in the case of spent fuel, P+T demands that some form of reprocessing takes place, and for existing reprocessing streams extra process stages, and possibly radically new techniques, are called for.

2. In the extremely simplistic diagram above, uranium and plutonium are shown recycled via Light Water Reactors, with other actinides and long lived fission products separated out at the reprocessing stage before a single stage of transmutation, either in a fast reactor or an accelerator-driven device. In actual schemes multiple
recycling stages are likely, with different final conditioning for different waste streams.

3. The various high level studies are almost universally agreed on several factors about Partition and Transmutation:

- P+T requires long lead times and high investment, extension of reprocessing facilities and remotely operated facilities for fuel and target preparation.
- There seems universal agreement that P+T technology is several decades away from production scale application.
- Partitioning of some actinides and long lived fission products could be achieved by extensions to current reprocessing operations (Np, Tc, I). Note that in the UK plant development timescales will curtail applicability unless THORP operation is prolonged.
- Partitioning methods have been developed on a laboratory scale, but much further development and scale-up work is needed.
- In the short term, P+T would reduce the long-term radiotoxicity of HLW but would entail extra plant operations, high inventories and more secondary wastes.
- Though P+T could have a beneficial effect on long lived radionuclide inventories, it would not remove the need for a long term management option for the residual wastes.

4. Key factors of this option, which will be discussed in Section 9, are:

K12.1 The technology required for many of the P+T operations contemplated is in its infancy and is unlikely to be available at industrial scale for at least 20 years.
K12.2 The cost is very high, with US programme estimates in the multi-tens of billions of dollars range. Cost estimates should be an early and significant element in any programme on this option.
K12.3 There is no legal or treaty obstacle to progress on this option.
K12.4 The nations most active in the field, the US, France and Japan, are all also active in progressing geological disposal.
K12.5a There seems to be international agreement that P+T cannot remove the need for a long term management option for remaining wastes.
K12.5b The current UK waste conditioning operations are reducing the possible applicability of this option.
3.13 Option 13. Disposal in Space (including solar disposal)

1. In this option, waste is packaged, as a minimum, to withstand acceleration from ground to escape velocity in rocket or shuttle. At least eight concepts have been examined, ranging from placing waste in high earth orbit, in solar orbits, to solar impact.

2. Analyses of costs have generally restricted consideration of this method to individual waste fractions (e.g. transuranics only) after reprocessing. Disposal of bulk waste (especially the large mass of UK ILW) by this method would be extraordinarily expensive using current technology.

3. As the UK is a very minor player in launch technology development, this option would of necessity need to be international. The option would almost certainly involve international transport.

4. Key factors of this option, which will be discussed in Section 9, are:

K13.1 The launch technology required for this option is not available to deal with the scale of payload represented by the UK inventory.

K13.2 The cost, for any of the waste streams currently contemplated, would be very high.

K13.3 The option is not prohibited by law but international space law imposes onerous liability on operating states should damage arise on earth or in space.

K13.4 The range of possible international partners is limited. Only France/ELDO, US, Russia, Japan and China currently have programmes for launch technology development. No other nation is currently considering this option.

K13.5 The adoption of this option would place a very high premium on weight.
reduction of waste. Current UK waste practices, involving vitrification and cementation, involve large weight increases, and are very far from the optimum for the space disposal option. The current programmes of solid waste conditioning are therefore decreasing the applicability of this option difficult in the UK.

3.14 Option 14. Dilute and Disperse

1. All operations with radioactive materials will involve some discharges to atmosphere, land or water, and these discharges will disperse and be diluted by natural mixing processes. The radiation from the materials can be absorbed by animals and plants giving doses which can cause detrimental effects. As has been already discussed, the harm caused is presumed to be proportional to dose, and the doses, and hence the risk and detriment, can be modelled.

2. If a level of risk is deemed to be tolerable, then it is plausible that large amounts of radioactivity could be dispersed into the environment in such a way that they were diluted to the extent that the tolerable risk level was never exceeded. However, the radiation and environmental protection principles discussed in Sections 2 and 4 of this report cause operators in the UK to use a process which represents the Best Practical Environmental Option, Best Available Technology Not Entailing Excessive Cost in plant design, and Best Practical Means in plant operation. The relevant standards effectively remove Dilute and Disperse as an immediate method of managing significant quantities of radioactive waste.

3. However, any long term method of waste management which cannot guarantee total isolation of radioactivity until decay is complete will release some of its radioactivity. This will then disperse in the environment by the same processes as current discharges. In effect, the regulations covering long term waste management are targeted at ensuring that the doses received in the long term are kept to the same or lower levels as would be permissible for prompt discharges.

4. Modelling in the long term for some of the options discussed, might demonstrate total detriment greater than those predicted from than the prompt dilute and disperse option. This could be a useful yardstick in the judgement of these options.

5. Key factors of this option, which will be discussed in Section 9, are:

K14.1 The technology and plant operation for justified discharges are defined in regulatory principles (see section 4).
K14.2 The cost of discharging radioactivity to the environment is low, but under current regulatory regimes can apply to only a very small amount of the waste inventory after appropriate abatement technologies have been applied.
K14.3 The amount of waste which can be directly discharged is subject to national and international agreements and regulations.
K14.4 Pressure from other states through treaties such as OSPAR will further restrict the availability of dilute and disperse as a disposal method.
4. Principles, Government Policy and Societal Concerns

4.1 Sustainable Development

1. The Government is committed to holistic management of the environment. Any policy for the long-term management of radioactive waste must, therefore, be in accordance with the general principles of environmental management espoused by the Government in line with its commitment to international environmental principles. Foremost amongst these is the principle of sustainable development, which is most usually defined in terms of its exposition in the Brundtland declaration as “development which meets the needs of the present without compromising the ability of future generations to meet their own needs”.

2. The principle was endorsed and developed at the Earth Summit in 1992 and there is now an international Commission on Sustainable Development. At national level, the Government has set up a succession of advisory bodies of which the present incarnation is the Sustainable Development Commission. The principle is easier stated than explained, however, and much has been written on different types of sustainable development (so-called weak and strong) and the relative importance of environmental, economic and social development.

3. The concept of intergenerational equity and the problem of giving legal effect to it present particular difficulties in the field of radioactive waste management given the long time scales involved. An extremely large number of generations could be effected by radiation emanating as a result of today’s waste management policies.

4. Because of the considerable uncertainties ensuing from such a long time scale, it is immediately apparent that invoking the principle of sustainable development is not necessarily helpful as a tool for choosing radioactive waste management policies. If the waste could be completely removed from the human environment by expelling it into outer space, for example, this would avoid burdening future generations but at what cost to the present generation? Similarly, if we use our best technology and decide to dispose of the waste in a deep underground repository where it is, effectively, out of human reach, are we frustrating future generations from being able to deal with the waste more effectively or even more usefully?

5. On the other hand, if we adopt a policy of long-term safe storage, such that future generations can access the waste if and when they develop appropriate technologies, we are putting future generations at risk of exposure arising from a breakdown in storage facilities. It would seem, then, that sustainable development cannot be used as a definitive criterion for distinguishing between options. All serious options must be defendable on grounds of sustainable development but it may not be possible to rate options one against another in this way. Instead, it is likely that the component principles of sustainability, including those covered below, will provide more effective tools for distinguishing between options.
4.2 Best Practicable Environmental Option

1. When there is more than one option available to deal with a problem of environmental pollution, it is commonplace to adopt the principle of the best practicable environmental option (BPEO). This concept was first included in English law in Part I of the Environmental Protection Act 1990 and was the subject of a detailed investigation by the Royal Commission on Environmental Pollution. It presupposes that more than one option is available to deal with a particular problem and, therefore, implies that this question has been asked, as it is in the present situation. It then requires some sort of comparison between the options in terms of their environmental effectiveness and their practicability. Practicability is a difficult term to define but is generally taken to include an element of cost effectiveness. The word “best” implies a single best option but this need not be the case. The comparison is unlikely to be that precise and, in any event, the differences may be largely subjective in some cases. Although the principles arose in environmental law, the idea of a best practicable option can be used more widely and there is no reason why it could not be used to assess options for health and safety as well.

2. The most difficult aspect of determining the BPEO is evaluating the importance attached to social values. This is most usually done using some form of Multi Attribute Decision Analysis (MADA) in which various selected characteristics are scored one against the other. The process of undertaking a MADA can be highly informative for the participants but it suffers from the major drawback of being less than transparent and difficult to explain to the outside world.

3. The determination of the BPEO is clearly constrained, in the first instance, by the range of options under consideration. It is generally used to apply at the general level rather than the specific, however. So, a question as to whether a pollutant should be emitted via a factory chimney or in an aqueous discharge to the sea would be a matter of determining the BPEO. Selecting between two processes, both of which would result in aerial emissions, on the other hand, would not. Such a selection would come down to the next level of refinement, the choice of the Best Practicable Means (BPM).

4. For any option to be implemented as BPEO, it must necessarily meet appropriate national and international safety and legal requirements. For the long term management of radioactive waste, the activities thought necessary to achieve this are contained in the work packages derived by the methodology of the current project. The current Government policy review may only need to establish that on balance an option or combination of options is clearly ahead of other options/combinations and that there is a strong enough probability that it will meet the necessary standards to proceed with confidence to select the option as BPEO. This is because all the waste- and site-specific circumstances cannot be known in advance of a specific scheme being defined. Much further work on meeting all appropriate requirements must then be done while the chosen policy is being implemented, possibly over a period of 25 years or more.

4.3 Best Practicable Means and other related principles

1. The need to apply the BPM is a common condition in control of pollution authorisations. In essence it requires an operator to use the most effective means
available to deal with the problem. In European and English pollution control law, it has been given greater precision in the form of the BATNEEC principle (best available techniques not entailing excessive cost). The phrase is highly subjective, with “best”, “available” and “excessive” all open to question. Guidance issued by the Government in respect of Part I of the Environmental Protection Act 1990 attempted to explain each term.

2. “Best” was not to be regarded as a single peak; in some circumstances it would be possible to have a number of options that were equally good, in other words they had passed some sort of threshold of “bestness”. “Available” was explained as obtainable and not just immediately to hand. If a process or technique was in use and could be acquired on the open market then it was available. “Techniques” in the English version of the principle is sufficiently broad to include work practices and training, etc. and not just technological attributes. In other EU member states a term equivalent to technologies is used instead. “Excessive cost” implies a balancing exercise. It is sometimes explained in terms of diminishing returns – paying an extra £100 to cut pollution by 50% is less likely to be excessive than paying an extra £1000 to cut it by just 5%, for example. At the end of the day, however, the selection of BATNEEC must involve an element of subjective judgement.

3. It is assumed that the evaluation of options for the long-term management of radioactive waste will involve both a determination of BPEOs which will, in turn, be based on an understanding of the BPM for each option. The use of BATNEEC, or its equivalent, would then be expected for any option that was implemented.

4. BPM and BATNEEC are process-driven principles, designed to force continued improvement in standards. It is also possible to exercise pollution control through quality standards and, indeed, this is commonly done across a range of environmental sectors such as air quality and freshwater quality. The quality standard adopted in the field of radioactive waste, however, is a health and safety standard. The dose of radioactivity arising from an authorised activity must be as low as reasonably achievable (ALARA) or as low as reasonably practicable (ALARP). It is arguable that these two terms do not differ significantly. The overriding importance of the ALARA principle is likely to have significant influence on the outcome of a BPEO evaluation because different options are likely to differ with respect to their human impact.

5. On the face of it, ALARA incorporates a protection against the law of diminishing returns by the inclusion of the word “reasonably”. There is a tendency, however, when dealing with calculated numerical risks to human life, to push achievability down as low as possible. The question of a threshold level, below which it can be assumed there is no risk, has proved difficult to address with respect to radioactive waste. Because it is known that the dose effect is linear and because it is possible to be highly precise in measurements of radioactivity, there has been a reluctance to accept a cut off point. In practice, achievability must eventually become unreasonable but there is no clear agreement as to the level at which this should occur. Instead, there is confusion between different requirements under different legal regimes.
6. Radiation protection in the particular case of the disposal of radioactive waste is covered by ICRP recommendations\(^{44}\), which embody the principles discussed above. For ILW and LLW disposal this has been interpreted for the UK in the EA publication ‘Disposal Facilities on Land for Low and Intermediate Level Radioactive Wastes - Guidance for Requirement’\(^{45}\) which lays down standards for doses and risks from disposed waste. There is no similar guidance for HLW, but there is no reason to believe that different dose and risk standards would be involved.

### 4.4 Other Environmental Principles

1. The Government is committed to the Precautionary Principle which has been expressed as ‘the Precautionary Principle states that, when potential damage to the environment is uncertain but potentially significant, the government should be prepared to take precautionary action, even where scientific knowledge is not conclusive, if the likely balance of costs and benefits justifies it’\(^{46}\). The Precautionary Principle is a fundamental principle of European Law and is increasingly being used in international environmental agreements. Its status as a general environmental principle is such that it is close to becoming accepted as a principle of customary international law. It is essential therefore, that the precautionary approach is invoked where it is applicable.

2. Self-sufficiency in waste management is a fundamental principle of European environmental policy and has been applied in the international context primarily to prevent export of waste to countries with lower environmental standards. It needs to be considered alongside the related principle of proximity, which advocates the minimum transport of wastes. Given the special nature of radioactive waste and radioactive waste technology, the implications of these principles may pose particular problems for the cost effective management of such waste.

### 4.5 Risk

1. The assessment of the risks associated with the management of radioactive waste is crucial to the development of future policy. Risk can be expressed in terms of cost, human health and safety, technology, environmental consequences, etc. Most importantly, even where risk can be quantified in numerical terms in an objective manner, it is the public perception of risk, an essentially subjective assessment, that is of particular importance in the field of radioactive waste management.

2. There has been a considerable amount of research into the nature of risk and its assessment. In its early work on the topic, the Royal Society\(^{47}\) attempted to distinguish between objective risk and perceived risk. Risk in this context was defined as the probability that a particular adverse event occurs during a stated period of time, or results from a particular challenge. According to Adams\(^{48}\), however, most

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\(^{46}\) The Precautionary Principle, Policy and Application, The Interdepartmental Liaison Group on Risk Assessment, 2002

\(^{47}\) Royal Society, ‘Risk Assessment’ (1983)

people understand risk to mean a measure of actual harm or loss associated with an adverse effect. In this sense it is an integrated product of risk and harm. In safety literature, risk is defined as the probability of an adverse future event multiplied by its magnitude. By 1992, the Royal Society\textsuperscript{49} appeared to acknowledge that risk is culturally constructed and stated that the distinction between objective and subjective risk was no longer a mainstream position.

3. Adams presents a theoretical model of risk compensation which postulates that:

- Everyone has a propensity to take risks.
- This propensity varies from one individual to the next.
- This propensity is influenced by the potential rewards of risk-taking.
- Perceptions of risk are influenced by experience of accident losses – one’s own and others’.
- Individual risk-taking decisions represent a balancing act in which perceptions of risk are weighed against propensity to take risks.
- Accident losses are, by definition, a consequence of taking risks; the more risks an individual takes, the greater, on average, will be both the rewards and the losses he or she incurs.

4. Scientific uncertainty about the physical world, the phenomenon of risk compensation, and the interactive nature of risk all render individual events inherently uncertain. “Risk” and “uncertainty” were distinguished as technical terms by Knight as long ago as 1921:

- Risk – if you don’t know for sure what will happen, but know the odds;
- Uncertainty – if you don’t even know the odds

5. In common, non-technical language, however, the distinction between risk and uncertainty is frequently blurred.

6. Risk avoidance is not an unequivocally good thing. For example, Adams refers to the phenomenon of excessive prudence, part of the balancing process against excessive risk taking. He notes the problems it can cause, including, for example, waste of money constructing buildings designed for stresses with which they are unlikely to have cope, and excessive safety, as on the railways where a spate of accidents has led to excessive safety measures and, therefore higher fares, thereby encouraging people to choose the more dangerous option of road transport. The potential to overcompensate for risks associated with radioactive waste management is clear.

7. There are long-running intellectual arguments on the acceptability of risk. Adams believes that the type of personal behaviour – whether the person is a fatalist, a hierarchist, an egalitarian, or an individualist, for example, mean that the arguments come from different premises. Cultural theory suggests that risks are viewed through cultural filters.

\textsuperscript{49} Royal Society ‘Analysis, Perception and Management’ (1992)
8. Adams refers to the greenhouse debate as an example of people arguing furiously in the dark with participants exhibiting biases characteristic of the stereotypes of cultural theory. Scientific disagreement and the lack of empirical data provide a fertile breeding ground for the development of biases. The fatalist shrugs and smiles, amused by the exertions of those trying to make sense of an unpredictable universe. The egalitarian looks for confirming evidence. The egalitarian precautionary principle transforms uncertainty into cause for urgent action. Individualists believe that nature is benign and robust and believe the ‘evidence’ is all down to natural variability. He or she would be likely to argue against the precautionary principle because it is indiscriminate and because it could prove financially disastrous. The hierarchist is alarmed by the climate record but does not panic. He or she favours a constrained view of the precautionary principle and advocates more research to devise effective management strategies. He or she brings the same scientific/managerial approach to the threat of global warming that he or she brings to all risks despite its unprecedented scale. Adams labels this section “Arguing in the dark”, a description reminiscent of some of debates over the long-term management of radioactive waste. He goes on to say the following in a postscript to the chapter:

“For a wide range of debates about risks, there is little or no prospect of science settling the issue. We are all confronted by the need to make judgments about potential risks on the basis of inadequate evidence. At times there appeared a danger of the introspection inducing total paralysis. It is easy to demonstrate that people are arguing from different premises, but if science is incapable of forging an agreement about premises, what more can one say?”

9. Adams goes on to consider the relationship between risk assessment and scientific uncertainty. Adams discusses the work of Beck and Wildavsky whom he describes as two of the world’s most eminent risk theorists. Beck argues that modern science and technology have created a risk society in which we quest for safety rather than wealth. Wildavsky is more optimistic in outlook. They are in reasonable agreement, however, as to the way forward. Beck puts his faith in science which he concludes needs to be better, more critical and with improvements in the conduct of scientific debates. Wildavsky notes that great differences in perception do not signify that all are equally in line with the evidence. Though each of us may perceive what we wish, we cannot necessarily make nature comply. Nevertheless, it is worth trying to create more knowledge and more agreement on what counts as knowledge.

10. Adams goes on to ask how this critical science is to be achieved. How can we create more knowledge and agreement about what counts as knowledge, he asks. Can we know the risks we face, now or in the future? No, we cannot; but yes we must act as if we do. As Adams explains, “as if” is ambiguous. Some act knowing that their knowledge is incomplete. Others manage to conjure certainty out of ignorance. Those advocating a scientific approach to risk act as if uncertainty is a temporary condition that can be resolved by further research. They, therefore, avert attention away from the question of how to act in the face of uncertainty by focusing their attention on the impossible task of removing uncertainty. He points out that the plea for more information does not get us very far. He discusses the democratisation of risk and states that decisions about risk are essentially decisions about social priorities and the values by which our societies wish to be guided. To exclude the bulk of the
population from these fundamental choices would be to ensure neither the equity nor the effectiveness of regulatory policies. It is common in cases of genuine uncertainty for the perceptibility of hazards to be much clearer to non-scientists than to scientists. The specialist knowledge of safety experts is confined to their specialisms and the narrower and deeper the specialism, the more often knowledge assumes the form of a heightened awareness of ignorance. For purposes of everyday coping we all get by with crude abstractions shaped by our beliefs. The hope that science will significantly alter this state of affairs is wishful thinking. It is a fallacy to confuse reality with one’s abstractions (paradigms, ideologies, beliefs) – the set of assumptions about reality formed through shared experience, supported by our associates and routinely unquestioned. They are culturally constructed and culturally maintained. Long-running disputes about risks almost always turn out on close inspection to be long-running because the participants are arguing from different premises.

11. Adams concludes with the following summary remarks:

- Remember, everyone else is seeking to manage risk too.
- They are all guessing; if they knew for certain, they would not be dealing with risk.
- Their guesses are strongly influenced by their beliefs.
- Their behaviour is strongly influenced by their guesses, and tends to reinforce their beliefs.
- It is the behaviour of others, and the behaviour of nature, that constitute your risk environment.
- Safety interventions that do not alter people’s propensity to take risks will be frustrated by responses that re-establish the level of risk with which people were originally content.
- In the absence of reductions in people’s propensity to take risks, safety interventions will redistribute the burden of risk, not reduce it.
- Potential safety benefits tend to get consumed as performance benefits.
- For the foreseeable future, nature will retain most of her secrets, and science will continue to invent new risks.
- Human behaviour will always be unpredictable because it will always be responsive to human behaviour – including your behaviour.
- It will never be possible to capture “objective risk”, however powerful your computer, because the computer’s predictions will be used to guide behaviour intended to influence that which is predicted.
- In the dance of the risk thermostats, the music never stops.

12. This dip into the literature on risk is included because it highlights the importance of distinguishing between its perception as a scientific and a subjective concept. There are, of course, numerous other writings on risk, which would need to be examined in detail in any further research but Adams provides a good basic overview of the general issues.
13. Managing the risk associated with radioactive waste must be a fundamental objective of any long term policy. Assessment of each of the options will necessitate an evaluation of perceived risks in each case.
5. Law Treaties and Obligations

5.1 Why do we need to ask questions about law?

1. The purpose of law in the context of radioactive waste management is to reduce risk to people and the environment. It is useful to identify at the outset those areas where law bites and therefore indicates a potential “problem area”. The main points of interface between law and radioactive waste management are listed below:

- Package and store the waste to keep it safe – the law needs to know that package and storage is robust and will behave as predicted; this requires scientific surety – i.e. packaging and storage will be legally acceptable if the relevant authorities say it meets the appropriate standard.
- Transport the waste – principles of minimising waste transport; large or small loads; national and international; transport standards, safety; routes; international concerns; transboundary issues; liability for damage.
- Where to put the waste (site issues) – satisfy scientific standards; meet local and national democratically voiced needs; satisfy other states; meet import/export obligations.
- Storage or disposal – hands on or hands off; balancing vagaries of human control against dangers of once and for all action. Legal requirement will be for authority to accept that the option will satisfy defined standards which are likely to be dose related (and hence related to risk). Law cannot address the uncertainty of the long term future but is likely to require a system of long term institutional overview.
- Involving other countries – international options and options affecting other states will need to satisfy international agreements designed to protect these parties. For cooperative ventures, law will require an indication of where the liability is to rest.
- Global commons – a sensitive area; common heritage of mankind; common interest of mankind; question of international relations; no sovereignty; high seas; space.
- Refining policy – generic policy should logically lead to specific proposals. In practice this might not work because there may only be one specific option for a line of policy and also because you need to explore the specific options as part of the formulation of the general policy. The issues are largely political and societal. It would be possible to devise a legal regime that allowed for a stepwise approval of a policy but it must be remembered that Parliament cannot bind itself and no modern law is set in tablets of stone.
- What could go wrong? – radioactivity could leak out of package or come back to man’s environment and cause pollution. This could be gradual or acute. There could be damage to human health and life and possibly to the wider environment. The law’s general response is to consider apportionment of liability but the concerns here appear to be ethical rather than legal. The legal approach will, therefore, be to minimise the chances of leakage through management regimes incorporating monitoring and feedback.
- What sort of law? – safety law is generally scientifically based with quantifiable standards etc. The use of dose standards (which are therefore related to risk) is likely to be maintained and all options would need to meet these. Whether this is the best standard for the long term management is a
different matter given our lack of knowledge about the world and the people in it far into the future. It might be better to adopt general environmental law methodology determined by environmental quality. This might impose emission/discharge standards and, therefore, a reassurance that these could be complied with. The proposal assumes ongoing monitoring. Note that the environmental law regime includes adherence to a number of broad principles of relevance to the long-term management of radioactive waste – polluter pays principles, precautionary principle, sustainable development, waste minimisation, self-sufficiency, etc. – which because of their imprecise definition may prove difficult to accommodate in an equally imprecise long-term management regime.

2. Overall, the role of law in long-term radioactive waste management is to try to maintain defined standards of health and safety and of environmental quality. Given a clean sheet, it would no doubt be possible to devise an optimal legal regime. Unfortunately, law and policy are not developed in a vacuum. One of the major downsides of environmental law, in particular, is its holistic approach in theory, matched by a sectoral approach in practice. This means, for example, that a detailed regime for waste management has been developed independently from the general regime for waste management which, itself, is an amalgam of safety and environmental law. Other areas of law that need to be considered include planning law, environmental impact assessment, transport law, and common law liabilities. Under international law, those treaties of specific relevance to radioactive waste must be interpreted against other agreements concerned with sovereignty and environmental protection, especially in the case of global commons.

3. It is important to consider legal questions alongside the more usual scientific ones because of the close interrelationship between the two. Thus:

- For the most part, policy on radioactive waste issues is implemented, or at least underpinned, by legislation and not merely through administrative decisions.
- At the international level, legislation on radioactive waste issues reflects agreed international political objectives.
- At the national and local levels, legislation provides the framework for implementing the policy and can, itself, impose constraints because of this.
- The nature of the legislation relating to radioactive waste provides an indication of society's concerns with respect to this issue.
- Legislation is not necessarily permanent. Laws are consolidated, amended, repealed and replaced. All of these changes give an indication of society's changing views on the adequacy of the legislation at any one time.

5.2 What questions do we need to ask?

1. The types of question that need to be asked depend on the questioner's starting point. The most practicable approach is to start with the existing body of law and question its suitability to meet the demands of a long-term radioactive waste management policy. The following list gives an indication of the range of questions that might be posed. More specific ones could be identified for particular laws.
• Does the law comply with existing thinking on sustainable development and intergenerational equity?
• Does its implementation conflict with any government policy in this or any other area?
• Does its implementation lead to conflict with the needs to implement other legislation?
• How likely is it that the law would be changed?
• If change is necessary, can this be achieved quickly enough?
• Does the existing body of law include appropriate reference to the principles and objectives of radioactive waste management?
• Are these principles and objectives internationally accepted or is there room for several approaches?
• Does the law allocate appropriate responsibilities for implementation, enforcement and monitoring of effectiveness?
• Does the law deliberately or incidentally impose any constraints on the progress of developing a radioactive waste management regime?
• What difficulties have been encountered in working with this legislation?

2. The alternative, more idealistic approach, is to assume that there is, at present, no legal framework and to determine what new laws would be needed to give effect to new radioactive waste management policies. The advantages of using this approach, in addition to the above, are that it provides a way of checking that all points are covered and serves to identify the most important legal provisions.

3. The questions can be couched in very general terms as follows:

• What is the policy for which legal sanction is needed?
• How can law help to achieve that policy?
• Do we have the necessary laws in place?
• Do any existing laws hinder development of the policy?
• What new legislation is needed?

4. A similar set of questions could be formulated to cover discrete parts of a policy or to examine the practicability of following any one of the potential options for long-term management.

5.3 What type of law is involved?

1. Laws come in all sorts of shapes and sizes. For the purposes of this review, it is appropriate to categorise them into two different groupings - the political level at which they are made and the broad subject matter.

2. The level of law is particularly important because it has a bearing on the likelihood of bringing about a change in the law. The following levels are likely to be of relevance here:

• International agreements
• European Communities law
• National laws
• National and devolved administrations' regulations
• Agency consents and authorisations

3. The subject matter of the law is also of great relevance because of the way in which it aligns issues of radioactive waste management with other types of policy. Most importantly, although radioactive waste management is regarded as an environmental issue, generally coming within the competencies of ministers of the environment, much of the relevant law predates society's recent interest in environmental concerns. Its purpose is clearly in the health and safety arena rather than the wider environmental one. It is only in more recent years that environmental law and policy has begun to develop in the field of radioactive waste management. It has not, yet, become fully integrated within the environmental suite of policies. For example, despite the extensive body of European law on waste management, radioactive waste management is treated separately. The question is whether this remains a sensible separation.

4. The following list contains the main types of legislation that have a bearing on the implementation of a radioactive waste management policy. All of these can be broken down into sub-categories and all of them are undergoing change or are likely to in the near future. It is important to place any given piece of proposed or actual radioactive waste management law in its overall context.

• Health and safety law
• Pollution control law
• Development planning law
• Environmental assessment
• Environmental information
• Environmental liability

Lists of legal instruments can be found in Appendices 6 and 7. Particular attention is drawn to basic legal principles of radioactive waste law, rather than details of legislation, and to other legislation of a more general nature likely to have a significant on the development of radioactive waste management policy. A brief overview of the international legal framework is provided in the next section. National laws and regulations are not covered in the main text because, for the most part, they are concerned with the imposition of standards and the regulation of activities. Any option chosen will presumably be modified to meet these national requirements if necessary.

5.4 The International Legal Framework

1. International law is of considerable significance in the formulation of the long term policy for radioactive waste management for two important reasons. First, a number of the environmental principles behind law and policy developments in the area of radioactive waste management have been agreed at international level and have a degree of acceptance across the international community. Given the potential transboundary implications of some of the options considered here, it is essential that they can be seen to comply with these international principles or, at least, that departure from them can be justified.
2. The second reason for the importance of international law is its political significance. While international law is not enforceable in the way that national laws are, a state that chooses to breach its treaty obligations is sending a strong political message to other contracting parties. Where a treaty represents a measure of agreement between a number of sovereign states, it is unlikely that, without a dramatic change in governing regime, any country would be likely to take overt steps to go back on a treaty agreement. It is even considered frowned upon to back out before becoming fully committed, as President Bush’s decision regarding the Kyoto Protocol shows only too well. If a state wishes to depart from its previous treaty commitments, therefore, it is most likely to seek the approval of other states party to the original agreement, possibly through the conclusion of another agreement.

3. The international legal regimes that are of greatest relevance to long-term radioactive waste management include those laying down general environmental principles, in particular those emanating from or embodying the principles of the United Nations Conference on Environment and Development (UNCED), and those with specific reference to the management of radioactive waste.

4. International law in the nuclear field has been primarily concerned with safety. The Convention on Nuclear Safety, which came into force in 1996, is of interest because it touches on radioactive waste management and, more significantly, because it provides a model for the later Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste. Both Conventions were developed under the auspices of the International Atomic Energy Agency (IAEA) in response to the Chernobyl accident. The conventions have been described as conservative in approach and certainly do not include any ground-breaking environmental commitments. Nevertheless, they do give legal effect to the IAEA’s fundamental standards for safety.

5. The Convention on Nuclear Safety is concerned with the safety of nuclear installations, that is civil nuclear power plants up until such time as the spent fuel has been removed and clearance has been obtained for decommissioning. The Convention reaffirms the principle that radiation exposure to workers and the public should be ALARA and that no individual shall be exposed to radiation doses exceeding prescribed national dose limits. The same provision is included in the Joint Convention.

6. The Convention on Nuclear Safety makes little reference to environmental matters other than a requirement to evaluate the likely safety impact of a proposed nuclear installation on the environment. In addition, where shut-down is necessitated because a plant cannot be upgraded to meet safety requirements, the timing of the shut-down may take account of environmental impacts as well as the whole energy context and social and economic impacts. Radioactive waste is referred to directly under Operation. There is a requirement for the generation of radioactive waste to be kept to the minimum practicable, both in activity and volume and for treatment and storage to take account of conditioning and disposal.

7. There is no international treaty solely on the environmental management of radioactive waste. The nearest is the Joint Convention on the Safety of Spent Fuel
Management and the Safety of Radioactive Waste, which, as the name suggests, is primarily concerned with safety matters rather than general environmental concerns.

8. The UK is a party to the Convention, which came into force in June 2001. Compliance with its provisions is unlikely to preclude any option. The Convention is mainly concerned with ensuring that contracting parties adopt an appropriate legislative and regulatory framework for radioactive waste management facilities, including disposal facilities. It covers the following matters:

- General safety
- Siting of facilities
- Design and construction of facilities
- Safety assessment
- Environmental assessment
- Operational control
- Regulatory bodies and licensing
- Decommissioning
- Transboundary movement

9. The Convention provides simple definitions of disposal and storage, as follows:

- “disposal” – emplacement of spent fuel or radioactive waste in an appropriate facility without the intention of retrieval
- “storage” – holding of spent fuel or of radioactive waste in a facility that provides for its containment, with the intention of retrieval.

10. The treaty obligations are based on the IAEA’s Principles of Radioactive Waste Management (1995). The protection of the environment from radiological hazards is one of three objectives of the Convention, the others being society and individuals. The Convention incorporates some basic environmental principles. Thus Article 4 requires parties to take steps to “strive to avoid actions that impose reasonably predictable impacts on future generations greater than those permitted for the current generation” and to “aim to avoid imposing undue burdens on future generations”. The Convention does not provide any details of what form these steps might take.

11. Before commencing work on a proposed radioactive waste facility, including a disposal facility, contracting parties are required to ensure that a systematic safety assessment and an environmental assessment are carried out. No further details are given although the text does refer to the need to review assessments over time and update them if necessary.

12. Article 17 concerns institutional measures to be taken after closure of a disposal facility. It covers the preservation of records or location, design and inventory, the taking of institutional control measures such as monitoring or access restrictions, and dealing with any unplanned releases. The Convention does not refer to the length of time during which these measures are to be maintained and does not even make it a requirement to institute active or passive institutional controls.
13. Most of the details are left to the contracting parties and their own national legislation. Most of the responsibility rests with the regulatory body, which is entrusted with the implementation of the legislative and regulatory framework outlined in Article 19. This provides for the establishment of radiation standards, an enforceable licensing system including a prohibition against operating a facility without a licence, a system of inspection, documentation and reporting, and a clear allocation of responsibilities.

14. The usual operating standards are covered in Article 24 which requires parties to ensure that during the operating lifetime of a facility (i.e. prior to closure of a disposal facility) radiation exposure to workers and public shall be ALARA, economic and social factors being taken into account. There is no guidance on the relative balance to be given to these factors.

15. Article 27 gives force to the IAEA’s Code of Practice on the International Transboundary Movement of Radioactive Waste (1990) which was based on the requirements of the Basle Convention on Transboundary Movements of Hazardous Waste (1989) from which radioactive waste was accordingly excluded.

16. The export of radioactive waste is covered by the Lomé Convention 1989 which was signed up to by the European Community in 1991. The Convention applies to countries in the African, Caribbean and Pacific (ACP) regions. Article 39 requires the EC to prohibit the export, direct or indirect, radioactive waste to ACP countries and requires these countries to prohibit the import of such waste from whether from the EC or elsewhere. The only exception is for the return of processed waste. Similar measures are provided by the Bamako Convention 1991 which was agreed under the auspices of the Organisation of African Unity and bans the import of hazardous waste into Africa and imposes controls over the transboundary movement and management of such wastes within Africa. Hazardous waste is defined as including “all wastes containing or contaminated by radionuclides, the concentration or properties of which result from human activity”.

17. Further controls on the movement of radioactive waste are contained in Directive 92/3/Euratom on the supervision and control of shipments of radioactive wastes between Member States and into and out of the Community. Under Article 11, Member States are prohibited from authorising shipments of radioactive waste to a destination south of latitude 60°S; to non-European parties to the Lomé Convention; or to a third country which, in the opinion of the authorities in the country of origin, does not have the technical, legal or administrative resources to manage the waste safely.

18. Compared with other aspects of environmental management, the EU has relatively little regulatory control over the environmental aspects of radioactive waste management. Most of its regulations are concerned with safety in the form of basic safety standards. However, Article 37 requires Member States to notify the Commission of any discharges of radioactive substances that might cause contamination in another state but does not give the Commission a power of veto.

19. The possibility of disposing of radioactive waste at sea is covered in a number of conventions. The first of these, the London Dumping Convention 1972 introduced
progressively stricter restrictions. To start with, there was a global ban on the dumping at sea of high level radioactive waste. In 1983 the ban was extended to all radioactive wastes and the moratorium was extended indefinitely in 1985. Agenda 21, agreed at the Earth Summit, is less cut and dried in its approach. Paragraph 22.5(c) says that States should not promote or allow the storage or disposal of radioactive wastes near the marine environment unless they determine that scientific evidence, consistent with international principles and guidelines, shows that such storage or disposal poses no unacceptable risk to people and the marine environment. Although not legally binding and not directly pertinent to disposal at sea, the statement does suggest the possibility that radioactive waste and the sea are not necessarily incompatible.

20. The UN Law of the Sea Convention 1982 is a wide ranging treaty covering sea use and marine protection. It contains a number of provisions on marine pollution including a requirement for parties to take all measures necessary to ensure that activities under their jurisdiction or control are so conducted as not to cause damage by pollution to other States and their environment (Article 194(2)). Subject to general environmental commitments and express commitments under other international agreements, States have jurisdiction over the sea bed in their territorial sea, exclusive economic zone and continental shelf, in effect, up to a distance of 200 nautical miles from baselines. The sea bed beyond, in the high seas, is defined in Article 136 as the common heritage of mankind. This part of the convention is primarily concerned with the exploitation of mineral resources in the sea bed but does include some general provisions on the use of The Area, as the high seas sea bed is termed. There is no express exclusion of sea bed or sub sea bed disposal of radioactive waste but any activities must be undertaken for the benefit of mankind (Article 140), for peaceful purposes (Articles 138 and 141) and in accordance with rules for the protection of the marine environment (Article 145).

21. Of the regional environmental agreements, the most significant for this study is the OSPAR Convention for the Protection of the Marine Environment of the North East Atlantic (1992) and, in particular, the agreement made at Sintra in 1998. The Convention is concerned with marine environmental quality and radioactive substances are just one of a number of pollutants covered. This is an important point because it means that the objectives of the Convention are focused on a physical sector, the sea, rather than a process, such as the management of radioactive waste. For the purposes of OSPAR, therefore, BPEO must be assessed as meaning best for the marine environment.

22. The UK’s surrender of its declared possible future exemption from the provisions against dumping LLW and ILW at sea, made at Sintra, effectively put an end to any possibility in the near future of disposing of radioactive waste at sea. Previously, the UK and France had insisted on retaining the option for possible future use. There is now a permanent ban against any such disposal by OSPAR parties in the OSPAR area because of a unanimous decision to terminate the possible exemption for the UK and France. There would seem to be little chance of reversing this decision so, for as long as OSPAR remains in force, there would seem to be a regional legal prohibition against the disposal of radioactive waste at sea in the area covered by the OSPAR Convention. This does not mean that options involving sea disposal necessarily need to be rejected at the preliminary stage, however. OSPAR is about the sea, not about
radioactive waste. If it could be shown that disposal of radioactive waste at sea was
the BPEO and that it could be achieved safely, there would be every reason to seek a
fresh international agreement along those terms. Under the present political climate,
however, this is unlikely to be successful.

23. Sintra also imposes a regime of progressive and substantial reductions of
discharges, emissions and losses of radioactive substances to the marine environment.
Compliance with this regime, which is currently being discussed within Government,
could, influence the choice of processes for the treatment of radioactive waste prior to
storage or disposal. A consultation paper on a draft UK Strategy for Radioactive
Discharges 2001-2020 was issued in June 2000 and a final strategy was published in
2002. Note, further, that a binding Decision was made at the OSPAR Commission
annual meeting in Copenhagen in June 2000 to reduce and eliminate radioactive
discharges, emissions and losses, especially from nuclear reprocessing. The decision
requires an urgent review of current authorisations for discharges and releases of
radioactive substances from nuclear reprocessing plants, with a view to implementing
the non-reprocessing option for spent nuclear fuel management at appropriate
facilities and taking preventive measures against accidental pollution. Although this
decision does not bind the UK which, along with France, abstained, it does illustrate
the general line of thinking within OSPAR and adds further weight to the suggestion
that it will be difficult to change opinion within the confines of the OSPAR
Commission.

24. An international legal regime governing the exploration and use of outer space
has been established under the auspices of the United Nations. This does not make
direct reference to the possibility of disposing of radioactive waste in space but it does
cover issues such as liability for damage caused as a result of space activities and
makes special provisions for the use of nuclear supply sources in space.

25. The starting point is an agreement that space cannot be appropriated by any
nation but remains free for the use of all. The Moon Treaty goes so far as to declare
the moon and other celestial bodies as being the common heritage of mankind. The
purpose of exploring and using space is restricted to things of benefit to mankind.
Whether the disposal of radioactive waste in space would be construed at beneficial is
arguable but it certainly would not fit into the category of prohibited activities such as
defence.

26. Liability for damage arising from the launch of a space object rests with the states
that own the object, arrange the launch or own the facilities at which the launch took
place. Liability is owed to persons and states and reparation must return them to the
position they would have been in had the damaging incident not occurred. This
liability includes damaging occasioned to other objects in space. The potential of
accident during launching of a rocket loaded with radioactive waste is probably not
negligible which means that considerable care would need to be taken to reduce the
effect of such an accident. A UN Resolution of 1992 addresses this problem with
respect to the carriage of nuclear power supplies into space. It lays down strict
safeguards. It is also worth noting that the US National Space Policy states that space
nuclear reactors will not be used in Earth orbit without specific presidential approval.
27. It is a further requirement of the international regime, that space activities are conducted openly and transparently. Before undertaking any space activity with potentially harmful effects, a contracting party must consult with other parties. The implications here are that outer space could only be used as a repository for radioactive waste if international agreement could be reached. This might not be impossible, given a strong enough motive to dispose of the material and sufficient technological safeguards to minimise the potential hazards.

28. One further legal argument against the space option is the question of sustainable development. Shooting radioactive waste irreversibly into space is, to all intents and purposes, removing it from earth forever. Taking material away, however undesirable it may appear at the moment, hardly accords with principles of sustainability from a resources point of view. There is also the concern against polluting another environment. The 1979 Agreement states clearly that all care must be taken to avoid environmental pollution of space in general and makes specific reference to the possibility of radioactive pollution.

29. In an ideal situation, law would simply be the technique for implementing policy and would not influence the shaping of that policy. In the real world, however, politics and law provide the interface for the social and natural sciences. Understanding existing laws and their evolution can provide a valuable insight into what society might and might not accept in radioactive waste management policy. The gradual move towards openness and transparency in corporate governance is becoming enshrined in law, thereby underscoring the change in emphasis from the secretive procedures within the nuclear industry in its early days to the participative approach demanded now.

30. The starting point for any assessment of options for long term radioactive waste management must clearly be the identification of the options themselves. Before proceeding to a decision however, any selection process on scientific criteria should be paralleled with a selection process based on socio-legal criteria. In short, an analysis of the laws and legal institutions involved in radioactive waste management can provide a test of likely public acceptance.
5.5 Legal Constraints on Waste Management Options - Summary

Principles are nearly all broad enough for a range of arguments to be developed for and against any option. In practice the Government will need to review these arguments and adopt its own interpretation.

- **R** The option is not necessarily prohibited, but authorisation may be conditional on a case being made and agreements obtained.
- **X** Currently prohibited and would need a change in law.

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<td>UK Planning Law</td>
<td>R</td>
<td>R</td>
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<tr>
<td><strong>L10</strong></td>
<td>Law on Global Commons (7)</td>
<td>R</td>
<td>R</td>
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</tr>
</tbody>
</table>
1. Under Moon Treaty etc.
2. Including UNCLOS, and London Dumping Convention.
4. Including European Law, Bamako and Lome conventions
5. European Directive 92/3/Euratom
7. International regimes including UNCLOS, Antarctic Treaty and Space Law
### 5.6 Key Questions from Legal Assessment

<table>
<thead>
<tr>
<th>Number</th>
<th>Legal Assessment Key Point</th>
<th>Relevant Key Question or Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>L.01</td>
<td>Does the option comply with law and policy on sustainable development?</td>
<td>2c</td>
</tr>
<tr>
<td>L.02</td>
<td>Does the option comply with international space law?</td>
<td>Critical to Option 13</td>
</tr>
<tr>
<td>L.03</td>
<td>Does the option comply with the UN Law of the Sea convention?</td>
<td>Relevant to Option 8,9,11 and 14</td>
</tr>
<tr>
<td>L.04</td>
<td>Is the option compatible with commitments under OSPAR?</td>
<td>Relevant to Option 8,9 and 14</td>
</tr>
<tr>
<td>L.05</td>
<td>Would implementation of the option meet the requirements of Environmental Impact Assessment (EIA) legislation?</td>
<td>2g, Relevant to Option 1-6</td>
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<tr>
<td>L.06</td>
<td>Is the option compatible with regulations for the import and export of waste?</td>
<td>Relevant to Option 2,4,6,</td>
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<tr>
<td>L.07</td>
<td>Is the option compatible with regulations covering international transport?</td>
<td>Relevant to Options 2,4,6,8,9,10,14</td>
</tr>
<tr>
<td>L.08</td>
<td>Can the option be carried out in compliance with existing or anticipated safety standards?</td>
<td>2f, Relevant to Options 1-14</td>
</tr>
<tr>
<td>L.09</td>
<td>Will the option be affected by the current or anticipated UK planning law system?</td>
<td>2e, Relevant to Options 1,3,5,12</td>
</tr>
<tr>
<td>L.10</td>
<td>Is the option compatible with international regimes for the protection of Global Commons?</td>
<td>Relevant to Options 8,9,10,11,13</td>
</tr>
<tr>
<td>L.11</td>
<td>Is enabling legislation required to allow activation of the option?</td>
<td>Included as question 2n</td>
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</table>
6. Science and Technical Aspects

6.1 General Considerations

1. As discussed in Section 2, the risks and hazards of radioactive waste arise from the doses that it could give to humans or other organisms if the radioactivity in it were released. The various components of radioactive waste have different half-lives and therefore continue to be a hazard for longer or shorter periods. Thus the effectiveness of long term waste management options will be judged by their ability to ensure that any radioactivity from the waste escaping into the environment during the time that it presents a hazard does not cause unacceptable risk or detriment. Many radioactive wastes remain hazardous for many thousands of years.

2. There are two basic strategies in long term waste management. ‘Concentrate and contain’ strategies seek to bring the waste into a concentrated (usually solid) form and to store (or dispose of) it under conditions such that it will not escape into the environment. The hazard is concentrated, the potential risks should it come into contact with people or the environment is high, but provided this contact is unlikely the overall expected detriment is low.

3. On the other hand, ‘dilute and disperse’ strategies release the waste into the environment and rely on dilution in air or water to reduce the concentration of radionuclides to the point where risks, and total detriment, are kept acceptably low. In general, opinion, treaties and legislation have been moving to make ‘dilute and disperse’ less acceptable, and placing more emphasis on ‘concentrate and contain’.

4. With the exception of Option 13 (Disposal in Space), which removes the waste from the earth’s environment, all options employ a combination of containment and ‘dilute and disperse’ to keep risk and total detriment within tolerable limits. As already stressed, the ability to reliably predict risk and detriment, and the definition of ‘tolerable limits’, are at the very heart of any radioactive waste strategy.

5. In Figure 6.1 the schemes are examined against a spectrum of science and technology attributes relating to ‘dilute and disperse’ and ‘concentrate and contain’. The key points for individual options have already been discussed in Section 3, but the principles of the attributes are discussed here.
### Fig 6.1 Some Science and Technology Attributes of Waste Management Options

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</thead>
<tbody>
<tr>
<td>1. Relies on dilute and disperse (1)</td>
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<td>No</td>
<td>Yes</td>
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<tr>
<td>2. Relies on a solid wasteform</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>3. Radionuclide retention in wasteform contributes to safety case</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>~ (2)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>(3)</td>
<td>No</td>
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<tr>
<td>4. Waste packaging contributes to safety case</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>(4)</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<tr>
<td>5. The option relies on long term engineered storage</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<td>No</td>
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<tr>
<td>6. Engineered containment barriers contribute to safety case</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<td>Yes</td>
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<tr>
<td>7. Natural barriers contribute to safety case</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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**Notes**

1. For Options marked ~ there is a wide variation in the level of dependence on dilution and dispersal. However, this is liable to vary with individual schemes and is the object of controversy, so no ‘dependence order’ is attempted here.

2. Option 7 (Direct Injection) generally injects liquid waste and can be said not to depend on wasteform. However, some variants use injection of waste mixed with cement grout, giving a waste form which can have significant retention properties.

3. The waste form in Option 11 (disposal in subduction zones) may have a role in delaying release in the period before subduction occurs. Once subduction has occurred the original form of the waste becomes immaterial.

4. The waste packaging in Option 11 (disposal in Subduction Zones) may have a role in delaying release in the period before subduction occurs. Once subduction has occurred the original packaging of the waste becomes immaterial.

5. Option 12 (Partition and Transmutation) does not of itself depend for its safety on waste form, waste packaging etc.. It must however be deployed together with another option to manage remaining wastes, wasteforms and packaging will remain important even if P+T is deployed.

6. Some sub-seabed options utilise engineered barrier systems.

7. Engineered barriers in Option 11 (Disposal in Subduction Zones) may have a role in delaying release in the period before subduction occurs. Once subduction has occurred the original engineered barriers become immaterial.

8. The geological surroundings in Option 11 (Disposal in Subduction Zones) may have a role in delaying release in the period before subduction occurs. Once subduction has occurred the original geological situation of the waste becomes immaterial.
6.2 Reliance on Dilution and Dispersal

1. Apart from the tolerability of risk and detriment, which has already been discussed, the critical process in all areas of ‘dilute and disperse’ is the ability to credibly model the effects of discharges of radionuclides on people and the environment. Thus all options except Disposal in Space (Option 13) will to a greater or lesser extent rely on the national and international development and verification of environmental models, and the credibility of the dose/risk relationship used. This is reflected in the work packages derived for the options.

6.3 Wasteform and Radionuclide Retention

1. All options except Option 7 (Direct Injection) and Option 14 (Dilute and Disperse) depend on a solid wasteform. In all these cases except Option 13 (Disposal in Space), the ability of the wasteform to contain the radionuclides and delay their release into the environment in normal or accident conditions will offer an advantage in generations a safety case. The extent of this advantage varies with the Option and with the detailed concept used. For example, some geological disposal concepts which rely on the longevity of the waste container will gain little in safety case terms from a more retentive wasteform.

2. A highly stable, solid, corrosion-resistant waste form acts to increase the timescale and/or reduce the rate of release of radioactivity into the environment. Such waste forms (e.g. wastes encapsulated in cement or vitrified waste) effectively prevent any possibility of sudden massive releases of radionuclides from the waste, even under severe accident conditions. However, if disposal has taken place, these waste forms cannot prevent long term, slow leaching and transport of radionuclides by flowing ground water (Options 5,6,9) or into the marine environment (e.g. Options 8,9).

3. In the case of Options 2,4,6, and 8-11, the necessary transport of wastes, generally by sea, will virtually necessitate a mechanically sound solid wasteform to contribute to a credibly safe transport system.

4. As indicated by the bibliography, there is a very large body of work on wasteforms and their radionuclide retention properties. Much of this has been reviewed or is familiar to the project team. The work worldwide has been concentrated on the geological disposal options, and certainly in the UK only the geological disposal option has been heavily studied, and has concentrated on ILW, mainly conditioned using cement.

5. There has been considerable work on plutonium wasteforms, notably in the USA, but these relate to a disposability standard (the Spent Fuel Standard) which has no counterpart in the UK. Also many of the plutonium wasteforms suggested require technological development or at least ‘productionising’ before they could be deployed. There is recent literature in the bibliography and certainly the ease and desirability of the characterisation and production of a plutonium wasteform is a matter of current controversy. This area was covered by the HLW and Spent Fuel project and suitable R&D packages have been defined, and are broadened to other waste management options by this current project.
6. The possibility of depleted uranium wasteforms was also covered by the HLW and Spent Fuel project. The challenge here is very different, as indicated by the figure following 2.2.4. This shows that the radiotoxicity of the uranium, while less than the original ore, is extremely long lived. This is why the predicted dose from geological repositories is often dominated by their uranium content after long time periods. Little work has been performed on uranium wasteforms and the large mass of uranium involved would mean that declaring reactor and/or tails depleted uranium a waste would considerably increase the amount of work to be done on the identification of waste packaging for either storage or disposal.

6.4 Waste Containers

1. The role of the waste container can vary from merely allowing contamination-free handling, via being an integral part of a long term safety case, to being the prime element in such a safety case.

2. For example, in Geological Disposal (Options 5,6) a high integrity metal (or ceramic/composite) container surrounding the waste in the right geological environment can be predicted to provide complete isolation for long periods. In the case of geological disposal, periods of several thousand years are calculated for steel containers, and hundreds of thousands of years for copper containers. However, the ability to predict mechanisms of corrosion which will be active over these extended timescales is often questioned, and the credibility with which projections can be made is at the heart of the ‘confidence’ with which many of the disposal options can be put forward.

3. As well as their use as barriers to radionuclide migration, the containers can have a significant role in accident situations during the operation of long term waste management options. For example, suitable steel overpacks can not only provide a primary radiation shield, but can also remove the chance of the failure of containment from handling accidents during waste plant operation.

6.5 Long Term Engineered Storage and Issues of Societal Control

1. The storage of waste conditioned to modern standards has been carried out in the UK only for the past decade or so. However, there is every expectation that engineered storage can last for many decades, and current waste storage is planned for a 100 year-plus timescale as discussed in Section 2.4. There is also little doubt that current technology, if then available, could cope with refurbishing/rebuilding stores and repackaging waste as required.

2. If, however, indefinite storage is to become policy (Options 1-4) then the key factor will be the extent to which very long term factors are taken into account. For example, if societal breakdown is taken as a possibility, then human intrusion into waste stores will be a significant factor in any safety case, as it is for current near-surface LLW disposal. It is therefore the parameters set for the engineering by societal and regulatory policy assumptions, rather than the engineering itself, which will present unanswered questions.
3. In more general terms, once timescales lengthen to more than a few decades, however, there must be growing uncertainty that the expertise, financing and commitment will actually exist to ‘keep things safe’. When contemplating timescales of 100,000 years or more, which is the sort of period needed to allow the bulk of waste to decay to the hazard level of a natural ore body, it is surely incredible to assert that institutional control will persist without interruption. Thus a further measure of any waste option should be the expected detriment if institutional control breaks down.

4. The figure below illustrates the effect of the breakdown of effective societal control on the performance of waste management options.

5. A key field of study for any option depending on societal control will be the effect of the withdrawal of this control and the tolerability of those effects.

6.6 Engineered Containment

1. These barriers apply mainly to geological disposal in Options 5, 6, and 9. For disposal options, the waste emplacement areas and access tunnels within a waste repository can be packed with backfill materials such as clay or cement grout and sealed with concrete or other materials. These can act over extended timescales to limit the movement of groundwater in the vicinity of the waste. They can also retard radionuclide movement and control solubilities. However, it is crucial that the long-term chemical processes that should ensure the longevity of these barriers are understood.

2. Engineered barriers would have the benefit of being fabricated using strict quality control procedures using well understood materials. As a result, they are assumed to provide a highly reliable barrier, particularly for the initial period of disposal when the radioactivity levels are highest. It is not possible to guarantee that these barriers will not eventually degrade.
3. Thus the main factor affecting the effectiveness of engineered barriers will be the credibility with which their effectiveness in containing radionuclides can be modelled for the long times required for radioactive decay to take place.

6.7 Natural Barriers

1. Natural barriers at a site consist of the host geological formation and any overlying geological strata separating the host formation from the biosphere. This will include seabed sediments and sub-seabed geology for the relevant variants, plus the isolating and/or diluting effects of ice sheets or the deep ocean. Natural barrier mechanisms should be effective for extended timescales, and their behaviour should be well understood and predictable.

2. A vast amount of work has been done and published, both in the UK and internationally, on the effectiveness or otherwise of geological situations in retarding the migration of radionuclides in groundwater. The bulk of this work has been done on land-based repositories, and the level of work on sub-seabed, direct injection and subduction zones (Options 7, 9, 11) is currently at a more generic stage. The key to all further work, however, is the credibility or otherwise of the work to model current and long term radionuclide behaviour and hence dose, risk and detriment. As will be discussed in Appendix 7, the strength of consensus needed to produce a level of confidence in proceeding with a policy will be crucial. As geological disposal is the main option being studied world-wide it is this area which maximises the opportunities for international co-operation. It is also the area where natural analogues can be of most help in giving long-term credibility to modelling.

3. The geology of the UK is very varied, and the UK is hilly, wet and highly populated. There are good scientific arguments that much better conditions could be found if a global search were made, but the argument may centre on the availability of a host country, the ethics of using a non-UK site, and the amount of transport involved, rather than the science or engineering.

6.8 Criticality

1. Discussion so far has centred on dose brought about by radionuclide transport in the environment by natural processes (waste breakdown by weathering processes, movement in groundwater, etc.) and more mechanical movement by natural disasters, man-created accidents or terrorist action. Another process which must be analysed is the possibility of criticality during waste management options. Criticality is the state reached by a fissile material when its mass becomes sufficient to sustain a chain reaction.

2. Wasteforms such as ILW from Magnox, and potential waste forms involving plutonium contain enough fissile material that, were it brought together in the right geometrical arrangement, criticality could occur. In a regime of knowledgeable institutional control, these criticality hazards can be avoided. Without institutional control, or in disposal regimes, natural processes (either through the breakdown of storage regimes or material transport in groundwater during disposal) could act to bring to bring the fissile material together and cause criticality. There are various ways that this might affect man or the environment depending on how the criticality
occurred. Fortunately there have been naturally occurring criticalities which give some guidance for deep geological disposal, and other possible events will need to be convincingly modelled. It is important that the impact as well as the occurrence of any possible criticality event is taken into account.

### 6.9 Overall Waste System Performance

A successful long term waste management option will:

- Physically protect the waste from erosion or inadvertent human intrusion.
- Increase the time before radionuclides enter the biosphere to allow decay.
- Reduce the concentration of any releases reaching the biosphere so that they will not result in unacceptable risks to people or the environment.
- Ensure that any predicted releases will ideally occur where there is minimal opportunity for human exposure, though this, by apparently favouring unpopulated areas, may run counter to the concept of proximity.

### 6.10 Scientific and Technical Uncertainty

1. As has been mentioned in many of the preceding sections, the main area of uncertainty is the performance of radioactive waste management options over the long timescales required for the hazard of the waste to reduce by radioactive decay.

2. The degree of scientific and technical certainty which is required at any stage will be critically dependent on the option selection process being used and the position in that process. As has been previously stated, an effective process enables the concerns of relevant stakeholders to be surfaced at an early stage, so as to frame the issues which need to be addressed and the scientific and technical programme required to remove uncertainties. It is essential that there is adequate stakeholder ownership of the questions as well as the answers.

3. Only such an inclusive process will strike a balance between the two extremes of opinion: one of which holds that science can never give adequate certainty, and those who would continue scientific investigation indefinitely for its own sake. Both extremes automatically preclude effective decisions and action.

4. That said, scientific uncertainty will occur at all the levels of analysis from the identification of the processes involved in any option, through the modelling of its effects to the overall safety and environmental consequences of undertaking the option. The process is indicated in the figure below. These scientific uncertainties will need to be tackled objectively and openly at all levels so as to ensure understanding of the processes and the issues involved.

5. The figure below illustrates the multi-layered nature of the safety analysis of any waste management option.
6. The incorporation of all these stages into the sort of inclusive process discussed in Section 7 will be needed to ensure confidence in policy making. This will not be a simple task.
7. Public Acceptability

7.1 General

1. Considerable thought should be exercised when either seeking to engage with the general public as part of any consultation exercise or when interpreting “public opinion”. Defining what is meant by ‘the public’ is in itself a difficult task. Some consider the public to be represented by those NGOs which derive their support and funding from the public, while others maintain that public opinion can be, and often is, different from the policy positions of the NGOs. There is also a responsibility on policy makers to avoid choosing an option because of a public perception of low risk, if there is specialist perception, or a reasonable expectation, that it is in fact high risk.

2. Even opinion polling can support diverging views. Typically, issues can appear to be of low priority when addressed by unprompted polling, but can attract strongly positive or negative reactions in prompted polls. Any process of policy development for radioactive waste must be undertaken in the light of all the available data on the development of public acceptability, but must be sure to place all this data in its proper perspective.

3. When evaluating the options under consideration, whether a particular group of people tends to be supportive or against depends upon a range of factors, for example:

- Perceptions of the technical and scientific viability or appropriateness.
- Perceptions of risk.
- Social and political factors.
- The values and ethics that different people hold.
- The trust and confidence in the information provided and the information giver.

4. Perceptions of negative public opinion, whether justified or not, have greatly increased costs in the nuclear industry especially in the area of waste management policy. Costs are increased where delays exist during the development, licensing or construction of new processes or facilities. Experience has also pointed out the cost implications when site selection and planning issues lead to legal challenge and review.

7.2 UK Experience – the Longlands Farm Decision

1. The current position in the search for a UK long term waste management option has been characterised as one in which the current level of scientific knowledge is insufficient to generate public confidence and therefore Government approval of a deep disposal repository would not be obtainable. In fact, the refusal of the Rock Characterisation Facility Inquiry (RCF) at Longlands Farm in 1997 can be interpreted in various ways.

2. The NGO view, as detailed in Appendix 14, is that the refusal was due to a successful challenge to the status of the science involved, and the acceptance of the ‘green’ view that ongoing research into basic geological, engineering and chemical principles was preferable to building the RCF. However, the concept that such research might eventually produce an acceptable technology to allow the siting of a deep disposal repository was not challenged.
3. An alternative view is that the inquiry inspector sought to explore the process by which the Longlands Farm site had been selected for investigation, with an expectation that the site had been chosen to be ‘the best’ candidate for an eventual repository. Nirex had not claimed that Sellafield would be the best site geologically, but believed that, given an adequate investigation programme, it would prove to be satisfactory. The RCF was part of the technical programme to investigate the geological suitability of the site to host a disposal facility. The selection of the site had not been made solely on technical grounds, but in the pragmatic belief that a combination of technical and public acceptability factors gave it an improved chance of success.

4. This view contends that, in linking the RCF with an eventual disposal facility, the planning permission was judged against the level of scientific and technical knowledge required to support an application for a disposal facility. The science and data available at that time was only mature enough to support an application to gather more data, and the planning submission therefore failed.

5. This alternative view sees the planning refusal as a process failure, in which there was inadequate transparency in the investigation process being followed and inadequate public and stakeholder buy-in to the criteria to be met at each stage.

6. Opponents to the deep disposal concept have used the RCF decision as an indication that it will never be possible to obtain the necessary certainty about the science of geological disposal, and that therefore public confidence and acceptability can never be achieved. In such cases, reconciliation of vastly differing viewpoints is unlikely to be achieved by any evaluation of options based upon the assessment of information and different criteria, as illustrated below. Indeed, in some cases greater engagement does not lead to greater consensus, but to a greater polarisation of views.

7. In Stage 1, effort is directed to engage with public and stakeholders in an effort to increase consensus. There may, however, come a point where the differences of view that remain are so fundamentally values-based that further accommodation is not possible. This could represent the maximum level of confidence which can be achieved for any given option. At this point (Stage 2) a policy can only be taken forward while acknowledging that some disagreement, including any lack of scientific consensus, will remain and may lead to public protest.
8. A major process failure regarding the RCF experience was that the public and stakeholders were not involved from the start in defining the UK’s waste management strategy. Nor were they engaged about why it was important that it be implemented on the proposed timescale. In evaluating any of the options within the MRWS, the timeframes associated with storage or eventual disposal will have a bearing on perceptions of technological feasibility, risk, social and political factors and the underlying attitudes and values of people.

7.3 Public Engagement Processes

1. Members of the research team have extensive experience in “stakeholder dialogue” processes. This process, convened by an independent and credible third party facilitator, seeks to include parties who may be interested in the outcome of decisions within a particular area of policy. Stages in the process may include:

   Collective agreement about the issues to be discussed
   Bringing together of a range of participants representing a broad range of constituent groups and interests
   Agreed information sharing and the commissioning of joint research
   Production of agreed reports where areas of consensus and/or continued areas of uncertainty and disagreement are highlighted
   Recommendations made for future action or additional research to reduce uncertainty or to provide contingency planning.

2. Such a process or any of the other consultative techniques described in the MRWS consultation are to be welcomed as proactive methodologies to increase engagement in public policy decision making. However, such innovative techniques do not of themselves allow the “general public” to be involved. Where individuals or groups feel excluded from the decision making process, they will feel less confidence in any outcome of that process.

3. Successfully engaging with the public to provide Government with a high degree of confidence that decisions can be successfully implemented will be facilitated by the staged approach of the MRWS consultation. Such a level of public inclusion is not without difficulties but there is substantial research50 about applicable processes.

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50 E.g. Project Isolus Front End Consultation Report to MOD, CSEC, Lancaster University, September 2001
4. The figure above\textsuperscript{51} represents the spectrum of involvement in decision making techniques. All approaches are legitimate in their own right and any process of public involvement is likely to use several if not all of the techniques described below.

Information Giving: the decisions have been made and there is a unilateral announcement of intent or decision. Stakeholders and public have an opportunity to react.

Information Gathering: information is obtained using research techniques. Respondents have no opportunity to influence the process or the eventual use of the information obtained, but the aim is to inform decision making processes.

Consultation: views are sought on a prepared proposal. Consultees do not share, but may influence, decision making. The aim is to generate responses to enable decision makers to have some understanding of consultees’ reactions to the proposal. There is an intention to listen to responses and the potential for amendments to, or further developments of, the proposal.

Bounded Dialogue: The parameters of the dialogue are predetermined and may be tightly drawn. Dialogue aims to enable collaboration in the development of policy or strategy. Decisions will be taken by the body with primary ownership of the ‘problem’ but the decisions are closely and explicitly influenced by stakeholders participating in the process.

Open Dialogue: all stakeholders decide the parameters of the dialogue together. There is joint analysis of the issue and the process seeks to develop decisions that address the needs of all stakeholders rather than their positions. The decisions are shared by all stakeholders involved.

5. Another example of public engagement is to undertake a Front End Consultation which is designed to elicit the concerns of the public and other stakeholders through addressing the issue of “framing” by enabling participants in the consultation to

\textsuperscript{51} Richard Harris, Independent Mediator, Facilitator and Process Consultant, 2001
construct the problem in their own way. This helps to define what the problems and issues are, and what is important to how these are addressed. This can give pointers towards a number of different discussion, debate and deliberative techniques. It is therefore crucial that work is put in train to devise an optimum integrated process design which would deliver the required level of public engagement, and to engage stakeholders and the public in this process at the earliest opportunity.

6. The key step must be the definition of an integrated and inclusive engagement process appropriate to the task, and including such techniques as those discussed in MRWS: workshops, interactive panels, community advisory committees, citizens’ juries, consensus conferences stakeholder dialogues, local agenda 21 groups, regional sustainable development frameworks, economic valuation techniques, public meetings, public hearings and enquiries, open houses, deliberative opinion polls, research panels and the internet.

7. The timing and content of this integrated process will also be crucial in determining how and when the information needs identified by this project should be fulfilled. There is some UK evidence of success in this area, notably with progress to date on the ISOLUS programme to define the fate of redundant submarines. Another example is the radiological monitoring of railway lines under the Jointly Agreed Sampling and Monitoring Programme (JASM)\(^5\) within the BNFL Cricklewood Dialogue was set up by a group of stakeholders using an agreed contractor. This has achieved a wide credibility which had been completely lacking in a previous exercise commissioned directly by the Department of Transport.

8. Work for Nirex\(^5\) has highlighted that radioactive waste decision making has been affected by public mistrust of scientific institutions and the uncertainty of scientific risk assessments. There was an assumption that the admission of uncertainty undermines the policy of decision making. However, the authors suggest that the public are now more likely to see as authoritative, institutions which admit uncertainty and reflect this uncertainty into their decision making strategies.

9. Because of the long timescales involved in radioactive waste management options, recognising uncertainty makes it essential to be able to return to issues and to change decisions in the light of increasing knowledge, societal needs or changing priorities.

10. Having defined a credible process design, it is essential that this unfolds in a transparent way. In particular, proposals affecting particular areas cannot be addressed until the generic issues surrounding any particular waste management option have been resolved. For processes that are liable to meet resistance in a locality or liable to cause real or perceived environmental or socio-economic detriment, issues such as volunteerism, compensation, and veto will have to have been addressed in principle. Any potential operational site (including the existing nuclear industry sites) must have a transparent view of the siting criteria and the associated social and economic parameters which accompany the siting process. An inclusive siting process is to be encouraged.

\(^5\) see the-environment-council.org.uk website
11. The siting of the operations of any waste management option will determine the number and type of transport movements involved. These may heighten public concern along transport routes and could be a factor in deciding between options involving centralised or dispersed facilities.

12. The recent Government announcement about the LMA and the consequent White Paper in 2002, will be impacted by the MRWS consultation exercise. The UKAEA Quinquennial Review Stage 2 report, published in November 2001, provides some initial thoughts about the potential structure and remit of an LMA. This report states that:

“6.26 As HMG’s nuclear liabilities manager, the LMA would be in a unique position to offer advice on the cost and practicability of different policy options but we do not believe that it should otherwise be involved in the decision-making process – it seems to us that its involvement could potentially compromise the public acceptability of the decisions taken in the same way that past proposals in this area have been prejudiced by direct association with the interests of waste producers. There must be a strong case, however, for the LMA taking on responsibility for implementation once decisions have been taken and potentially extending its remit in that role to cover all UK radioactive waste.”

13. In addition to the LMA implementation, there are a number of key regulatory consultations and outstanding policy issues which will impact upon the technical implementation and therefore the public acceptability of the various options outlined in the INRP evaluation. There should therefore be a work stream to determine the interaction between these various consultations and any additional information requirements that could emerge.

7.4 International Considerations

1. All options considered will affect the environment of other countries to some extent. The predicted magnitude of this effect will vary very substantially between options. Public concern within countries outside the UK will be driven by a perception of harm and risk which may bear no relation to the predicted effects. Increased concern will be fuelled by the belief that at risk from an activity from which they receive no direct benefit.

2. The concept of ‘dilute and disperse’ as a method of waste disposal runs counter to the public belief that waste should be dealt with by those who produce at, or near to, the site of its production. This will give public acceptance problems to any option which uses dilution in the sea as part of its risk reduction mechanism.

3. For options involving the international transport of radioactive waste, this will become a significant factor in the public formulating its view of the acceptability of any particular management option.

### 7.5 Mapping of Public Acceptability Key Points onto Methodology for Deriving Overall Research Scope

<table>
<thead>
<tr>
<th>Number</th>
<th>Public Acceptability Key Point</th>
<th>Relevant Key Question or Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA01</td>
<td>Is the risk analysis believable and acceptable?</td>
<td>Included as question 4a</td>
</tr>
<tr>
<td>PA02</td>
<td>Is the implementation of the option part of a process which allows adequate public participation and stakeholder input to shape the process?</td>
<td>Included as question 4b</td>
</tr>
<tr>
<td>PA03</td>
<td>Is the process for choosing between different siting options transparent and designed to address both national and local concerns?</td>
<td>Included as question 4c</td>
</tr>
<tr>
<td>PA04</td>
<td>Is the implementation of the option part of a package which adequately values the contribution of the chosen locality in solving a national problem?</td>
<td>Included as question 4d</td>
</tr>
<tr>
<td>PA05</td>
<td>Are the environmental effects deemed to be morally and ethically acceptable?</td>
<td>Included as question 4e</td>
</tr>
<tr>
<td>PA06</td>
<td>Are the costs associated with implementing the option sustainable in the light of other competing social and environmental needs?</td>
<td>Included as question 4f</td>
</tr>
<tr>
<td>PA07</td>
<td>Ultimately, is the consensus (however defined) adequate to enable the policy to be pursued with confidence?</td>
<td>Included as question 4g</td>
</tr>
<tr>
<td>PA08</td>
<td>Perception of scientific and technical viability of the option.</td>
<td>3k,l, 3n, 3p</td>
</tr>
<tr>
<td>PA09</td>
<td>Scientific knowledge sufficient to give public confidence?</td>
<td>3k,l, 3n, 3p</td>
</tr>
<tr>
<td>PA10</td>
<td>Perception of risks associated with the option.</td>
<td>2g, 3k-n,</td>
</tr>
<tr>
<td>PA11</td>
<td>Public perception of the values and ethics of the option.</td>
<td>4e</td>
</tr>
<tr>
<td>PA12</td>
<td>Trust and confidence in information and the information giver.</td>
<td>4b</td>
</tr>
<tr>
<td>PA13</td>
<td>Transparency of the investigation process.</td>
<td>4b</td>
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<tr>
<td>PA14</td>
<td>Public and stakeholder buy-in to criteria for option selection.</td>
<td>4b</td>
</tr>
<tr>
<td>PA15</td>
<td>Early public and stakeholder involvement in the process of defining UK Waste Management Strategy.</td>
<td>4b</td>
</tr>
<tr>
<td>PA16</td>
<td>Timeframes associated with storage or eventual disposal</td>
<td>4b,c,d G07, G24</td>
</tr>
<tr>
<td>PA17</td>
<td>Resolution of generic siting issues e.g. volunteerism, compensation, veto.</td>
<td>4b,c,d</td>
</tr>
<tr>
<td>PA18</td>
<td>Transparency of siting criteria and site selection process.</td>
<td>4c</td>
</tr>
<tr>
<td>PA19</td>
<td>Transparency of social and economic parameters.</td>
<td>2h, 2i, 4f</td>
</tr>
<tr>
<td>PA20</td>
<td>Number and type of transport movements within the UK.</td>
<td>3t, G20</td>
</tr>
<tr>
<td>PA21</td>
<td>Number and type of international transport movements.</td>
<td>3s, G20</td>
</tr>
<tr>
<td>PA22</td>
<td>Interface with LMA.</td>
<td>2d</td>
</tr>
<tr>
<td>PA23</td>
<td>Interaction between MRWS and outstanding regulatory consultations and policy issues impacting technical implementation.</td>
<td>2d, 2f, 2g</td>
</tr>
</tbody>
</table>
8 Perspectives of Environmental Interest Groups

8.1 General

1. As is discussed elsewhere in this report, the process of decision-making in a manner which provides for a variable degree of confidence is neither mechanical nor formulaic. It is a complicated, iterative and time-consuming one which involves engaging, assessing and assimilating opinions from a broad cross-section of society. There are few sections of society more vociferous and capable of conveying their opinions than the ‘green’ organisations and an area in which they have historically been active and highly effective is that of nuclear waste management.

2. Green organisation activities terminated the practice of sea-dumping LLW and ILW. They have operated a decades-long campaign against reprocessing of spent nuclear fuel and, as a consequence, have had significant influence on radioactive waste discharge strategies. Most recently, they were instrumental in the failure to obtain permission for the RCF proposed by Nirex at Longlands Farm near Sellafield. In short, their opinions – and the impact their opinions can have on that of other sectors – are important. In the context of the INRP, key issues which could have an impact on the way in which the Government decides ‘with confidence on the long term management options for long-lived radioactive waste’ are explored below.

3. Some green, anti-nuclear organisations have historically argued that to collaborate with agencies engaged in finding and implementing a long-term solution to radioactive waste disposal is to perpetuate the conditions which encourage the creation of more radioactive waste, for which they have argued there is no acceptable solution, merely a ‘least-worse’ management option. For example, this has led Greenpeace to the policy of non-co-operation, to opposition to deep disposal and to the policy position of temporary – or possibly indefinite – above ground storage of waste in a monitorable and retrievable condition.

4. This policy continues, although the heightened awareness of the vulnerability of nuclear facilities following the attacks on the World Trade Centre on the 11th September 2001, has led some green NGOs to consider the possibility of sub-surface storage. Any process designed to arrive at a decision ‘with confidence’ – i.e. removing as much doubt as possible about the viability of a particular option – will still be subject to review and deliberation by the green organisations which have demonstrated their ability to influence public opinion. Green opposition could significantly erode public confidence in any proposed option.

8.2 Ability to adequately model releases to the environment and the consequent doses to humans

1. This issue is central to the green view of radioactive waste management. Any claim that releases from a waste management option can be adequately modelled at the current time will be countered by green organisations. Release rates and dose evaluation are presented by greens as being at the cutting edge of science and it is questionable if these tasks could ever be completed to a degree which would secure green organisation acceptance. The debate surrounding the effects of low level radiation are detailed in Section 2.1 and Appendix 5. The Royal Society, when
giving evidence on geological disposal to the House of Lords’ Science and Technology Committee enquiry into radioactive waste management, commented that decades of work remain to be carried out in this area. This concern would be replayed by the greens for disposal and other options.

2. As is acknowledged, the degree of uncertainty which exists in determining which materials will eventually form the waste inventory for management is significant. To adequately model to the level of certainty required, the release/dose relationship associated with any long term management option which goes beyond interim storage will be a key determinant.

3. Thus the resolution of the on-going debate over low-dose exposure to ionising radiation and decisions as to what level of exposure is acceptable or tolerable is a significant and possibly intractable area of disagreement. This could preclude green organisation buy-in to any long-term management option beyond interim storage.

4. Green organisations will point to the fact that through campaign pressure, ICRP reviews and pressure from other agencies, risk factors have been increased over the years and discharge levels have been forced downwards. Green organisations believe that this trend will continue and that, even without the pressure applied by low-level radiation campaigners, some tightening of current radiological protection standards are to be anticipated.

5. Greens would argue that:

- Standards could underestimate risk from ingestion of specific radionuclides (particularly actinides)
- The permitted public dose limit produces an unacceptable risk and the limit should be reduced.

8.3 Validation of data and consensus

1. Another area of green contention is the ability of a proponent of a particular management option to secure adequate peer review and scientific consensus. Scientific controversy regarding certain aspects of a proposed option not only creates a significant reduction of confidence in stakeholder views but is a key area of concern for greens. Indeed, in this respect, it is not the quantity of material available on a particular management option but the quality of that material and the level of consensus it enjoys within the scientific community.

2. As with every area of scientific endeavour, claims regarding validation and consensus can always be challenged and doubt introduced in respect of the detail and robustness of assumptions and modelling techniques. This was the case with the RCF when Friends of the Earth challenged the validation and peer review of the Nirex work on the geology and hydrology of the proposed site.

3. It could be argued that prior to the RCF inquiry, there was a high degree of scientific consensus that deep disposal was the best radioactive waste management option and that disposal near Sellafield was the most viable site, yet this was overturned, apparently by a few consultants of a different persuasion.
8.4 Setting a policy within the timescale of the DEFRA consultation

1. A potential source of opposition is likely to be the view held by some organisations that the remaining five years of the DEFRA consultation as outlined in MRWS is unrealistic. Given the historic attitude to radioactive waste management and the exclusive manner in which decisions were arrived at until very recently, green organisations harbour the belief that any drive towards a disposal policy is premature. They feel that any proposal beyond passive, interim storage with an indefinite time ahead in which to carry out the sort of definitive, co-operative and consensually-based research needed to embark on a disposal programme with confidence should, by its very nature, be opposed.

8.5 Site Specific Aspects

1. Any organisation opposed to a particular management option would use the local social, geological and hydrological conditions as tools with which to raise concern and opposition within the affected population. The level of confidence which may or may not have been identified in existing and yet-to-be undertaken generic research into any management option could become largely academic when these site-specific arguments are brought to bear.

2. In addition, many green organisations would argue that the geological conditions available in the UK will be unable to provide containment of waste for the periods of time required for the material involved, and that therefore disposal options should not be implemented.

8.6 Accuracy of the waste inventory

1. Accurate modelling of future characteristics and doses arising from a waste repository or depository is dependent on the degree of precision regarding the inventory and nature of the waste forms being modelled. Evidence submitted to the 1994 Review of Radioactive Waste Management Policy by green organisations contended that only 1.6% of radionuclide content of wastes arising from the activities of BNFL and the then Nuclear Electric had been measured. They submitted that the remaining 98.4% had only been estimated with ranges of uncertainty of up to 100 fold.

2. Thus any future management policy adopted would be vulnerable to criticism over the accuracy of the inventory and the resultant dose calculations arising from that inventory.

8.7 Plutonium

1. Within the green range of concerns, plutonium is of special significance and the decision as to its status is not only critical to deciding on any future management option but is also an area where greens will take a very definite stance.

2. Greens would argue that the fate of plutonium stocks in the UK should be subject to:
• Assessment of which immobilisation strategy produces the lowest occupational and environmental risk
• Which form is least vulnerable to terrorist diversion
• Which form best immobilises it in the most passive waste form.

3. As has already been noted in Section 2, plutonium represents a high percentage of the radiotoxicity of spent fuel, and declaring some or all of it as a waste would have significant effect on the criticality considerations of many options, together with issues relating to containment in both disposal and storage options.

8.8 Climate change

1. Any future waste management option would be vulnerable to criticism from the viewpoint that within the period envisaged in some quarters for interim storage (100 – 150 years) the climate of the UK could dramatically change. That change could – some say will – bankrupt the world economy and cause the breakdown of institutional oversight. This could result in a demand for an ‘end date’ by which all nuclear materials should be put into a passive state. This presupposes that no new nuclear material should be produced – i.e. no new nuclear build programmes and a much greater emphasis on renewables. However, some greens accept that nuclear power stations could make a contribution to reducing the impact of climate change.

8.9 Other issues of Environmental Interest Group concern

• Security from criticality, accidents, acts of terrorism
• Origin and robustness of policy
• Acceptable safety standards
• Compliance with best practice
• Compliance with scientific and sustainability requirements as set out in July 1995 White Paper Cm 2919 and A Strategy for Sustainable Development for the United Kingdom. Cm4345, May 1999
• Objectivity of research
• Degree of consensus
• Definition of consensus
• Regulatory agencies reactions
• Comparison of options on safety grounds
• Timing and foreclosure of options by conditioning practices
• Disposal routes not credible at present
• Ethical issues/intergenerational issues
• Transport issues
• No transfer of responsibility (in relation to international storage)
• Contain and concentrate, not dilute and disperse
• The morality of creating more of a material for which there is only a ‘least worse’ management option and no universally accepted disposal solution.
<table>
<thead>
<tr>
<th>Number</th>
<th>Key Points</th>
<th>Relevant Key Question or Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>G01</td>
<td>Current NGO policy supports above ground monitorable and retrievable passive storage.</td>
<td>Supports Option 1</td>
</tr>
<tr>
<td>G02</td>
<td>Post 11 September 2001, NGO Policy may support underground monitorable and retrievable passive storage.</td>
<td>Supports Option 3</td>
</tr>
<tr>
<td>G03</td>
<td>Ability to model releases and effects on people and the environment.</td>
<td>3k, 3l</td>
</tr>
<tr>
<td>G04</td>
<td>Standards could underestimate risk from ingestion of specific radionuclides.</td>
<td>3m</td>
</tr>
<tr>
<td>G05</td>
<td>Permitted public dose limit produces unacceptable risk.</td>
<td>3m, 3n, 4e</td>
</tr>
<tr>
<td>G06</td>
<td>Ability to secure adequate objectivity, peer review and scientific consensus.</td>
<td>4b – Peer Review and adequate scientific consensus to work packages.</td>
</tr>
<tr>
<td>G07</td>
<td>Timescales for policy formulation are far too short to allow for the research which would be necessary.</td>
<td>4b,c,d, timescale aspects to work packages.</td>
</tr>
<tr>
<td>G08</td>
<td>Site-specific concerns</td>
<td>4c</td>
</tr>
<tr>
<td>G09</td>
<td>UK geology cannot provide a suitable environment for geological disposal.</td>
<td>Opposes Option 5</td>
</tr>
<tr>
<td>G10</td>
<td>Lack of precision of waste inventory precludes accurate modelling.</td>
<td>3k,l, 3r. Inventory Accuracy to Work packages.</td>
</tr>
<tr>
<td>G11</td>
<td>Plutonium should be immobilised in the form which makes it most passive, resistant to terrorist diversion and giving the lowest occupational and environmental risk.</td>
<td>3i.</td>
</tr>
<tr>
<td>G12</td>
<td>Climate change may drive the breakdown of institutional control.</td>
<td>2a, 3c</td>
</tr>
<tr>
<td>G13</td>
<td>Safety of options with respect to criticality, accidents, terrorism.</td>
<td>2f,g, 3d,e</td>
</tr>
<tr>
<td>G14</td>
<td>Acceptable safety standards</td>
<td>2f,g, 3n</td>
</tr>
<tr>
<td>G15</td>
<td>Compliance with best practice.</td>
<td>3q</td>
</tr>
<tr>
<td>G16</td>
<td>Compliance with Scientific and Sustainability requirements as set out in Cm2919 and Cm4345.</td>
<td>2c, 2p, 4f</td>
</tr>
<tr>
<td>G17</td>
<td>Ability to meet regulatory standards.</td>
<td>2f,g.</td>
</tr>
<tr>
<td>G18</td>
<td>Timing and foreclosure of options by conditioning practices.</td>
<td>2q</td>
</tr>
<tr>
<td>G19</td>
<td>Ethical and intergenerational issues – including continued waste production.</td>
<td>2c, 4e, 4f</td>
</tr>
<tr>
<td>G20</td>
<td>Transport Issues</td>
<td>3s,t</td>
</tr>
<tr>
<td>G21</td>
<td>Opposition to transfer of responsibility beyond UK</td>
<td>Opposed to Options 2,4,6,8,9,10,11,13,14.</td>
</tr>
<tr>
<td>G22</td>
<td>Contain and concentrate rather than dilute and disperse</td>
<td>Opposed to Options 7,8,9,10,14</td>
</tr>
</tbody>
</table>
Section 9. Definition of Information Needs and Related Activities

1. The project methodology as outlined in Section 1 involved an initial series of ‘horizontal’ work packages covering various broad aspects of long term radioactive waste management. These are seen in Appendix 2 and comprise the examination of UK radioactive waste in Section 2, the description of the 14 long term waste management options in Section 3, and Government policy and related matters in Section 4. Legal aspects are reviewed in Section 5 and science and technology in Section 6.

2. Experience gained during these ‘horizontal’ activities allowed the development of a generic set of 47 questions which could be applied to all 14 options. These questions have been introduced in Section 1. Detailed answers to all questions for all options were then compiled and are given in Appendix 10. This exercise provided an initial scoping of the extent and complexity of the information which would be needed to take forward all the options to completion.

3. As mentioned in Section 1.5, ‘An R&D Strategy for the Disposal of High-Level Radioactive Waste and Spent Nuclear Fuel’ provided a research plan of 60 work packages for the waste type and option studied covering more than 40 years. The current project used this research plan as a template against which to scale the information needs of the 14 project options. This was done by examining each of the options against the 60 work packages, testing which were relevant to the particular waste management option. The results of this examination are given in Appendix 9.

4. Completion of the horizontal work packages produced lists of key points and questions which are given in the relevant sections and in Appendices 11-14. These could be expected to cover a similar field to the Generic Questions, but, having been generated later in the process, provided a further insight into information needs and complemented the next process: the generation of information needs work packages.

5. The mechanism used for this process is detailed in Appendix 8, and illustrated by the figure below.

6. All the answers to the Generic Questions, plus the key points generated from the horizontal work packages were attributed to the relevant HLW and Spent Fuel Packages as in Appendix 9. Some questions and attributes did not map onto these work packages and therefore new work packages were developed to satisfy these. This led to the complete work package attribute listing for all options given in Appendix 15, and summarised in Appendix 16.
7. The attributes of each individual work package in Appendix 15 were used to produce individual work package descriptions such as the example below, and descriptions for all 630 work packages are given in Appendix 18.
Option 1. Above Ground Storage

<table>
<thead>
<tr>
<th>Number</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>WP01.01</td>
<td>Ensuring openness and transparency in the development programme for Indefinite Above Ground Storage</td>
</tr>
</tbody>
</table>

**Work Package Attributes and Questions Addressed**

1.4b Is the implementation of the option part of a process which allows adequate public participation and stakeholder input to shape the process? *This option requires national buy-in to indefinite storage. It will entail heightened local awareness depending on site selection choices, and requires a process which addresses the planning, blight and compensation/reward aspects identified in 2e,h,i.*

1.4c Is the process for choosing between different siting options transparent and designed to address both national and local concerns? *This option requires national buy-in to indefinite storage. It will entail heightened local awareness depending on site selection choices, and requires a process which addresses the planning, blight and compensation/reward aspects identified in 2e,h,i.*

PA02 Is the implementation of the option part of a process which allows adequate public participation and stakeholder input to shape the process?

PA03 Is the process for choosing between different siting options transparent and designed to address both national and local concerns?

PA12 Trust and confidence in information and the information giver

G06 Ability to secure adequate objectivity, peer review and scientific consensus

PA13 Transparency of the investigation process.

PA14 Public and stakeholder buy-in to criteria for option selection.

PA15 Early public and stakeholder involvement in the process of defining UK Waste Management Strategy.

PA16 Timeframes associated with storage

G07 Timescales for policy formulation are far too short to allow for the research which would be necessary.

PA17 Resolution of generic siting issues e.g. volunteerism, compensation, veto.

PA18 Transparency of siting criteria and site selection process.

G08 G08. Site-specific concerns

**International Collaboration**

No

**Commentary**

This package is part of the overall activity of designing a process to take forward the UK Strategy on Long Term Radioactive Waste Management and feeds into the overall package 01-14.62. It requires to be integrated with the 01 Work Packages for all other options, and will run for as long as Option 1 remains in contention as part of the Strategy.
Section 9. Definition of Information Needs and Related Activities

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**Work Package Attributes and Questions Addressed**

| 1.4b | **Is the implementation of the option part of a process which allows adequate public participation and stakeholder input to shape the process?** This option requires national buy-in to indefinite storage. It will entail heightened local awareness depending on site selection choices, and requires a process which addresses the planning, blight and compensation/reward aspects identified in 2e,h,i. |
| 1.4c | **Is the process for choosing between different siting options transparent and designed to address both national and local concerns?** This option requires national buy-in to indefinite storage. It will entail heightened local awareness depending on site selection choices, and requires a process which addresses the planning, blight and compensation/reward aspects identified in 2e,h,i. |
| PA02 | **Is the implementation of the option part of a process which allows adequate public participation and stakeholder input to shape the process?** |
| PA03 | **Is the process for choosing between different siting options transparent and designed to address both national and local concerns?** |
| PA12 | **Trust and confidence in information and the information giver** |
| G06  | **Ability to secure adequate objectivity, peer review and scientific consensus** |
| PA13 | **Transparency of the investigation process.** |
| PA14 | **Public and stakeholder buy-in to criteria for option selection.** |
| PA15 | **Early public and stakeholder involvement in the process of defining UK Waste Management Strategy.** |
| PA16 | **Timeframes associated with storage** |
| G07  | **Timescales for policy formulation are far too short to allow for the research which would be necessary.** |
| PA17 | **Resolution of generic siting issues e.g. volunteerism, compensation, veto.** |
| PA18 | **Transparency of siting criteria and site selection process.** |
| G08  | **Site-specific concerns** |

**International Collaboration**

No

**Commentary**

This package is part of the overall activity of designing a process to take forward the UK Strategy on Long Term Radioactive Waste Management and feeds into the overall package 01-14.62. It requires to be integrated with the 01 Work Packages for all other options, and will run for as long as Option 1 remains in contention as part of the Strategy.
Section 10. Research Needs and Programme Resourcing

1. The INRP project has examined 14 waste management options, and a possible five waste types, to derive the detailed information which will be required, by Government after due consultation, in order to select with confidence practical management options for solid long-lived radioactive wastes. This has led to the identification of the 630 potential work packages contained in Appendix 18. The project has not considered the possibilities of different waste management options being adopted for the various waste streams, as the number of permutations becomes unwieldy. This added complication must, however, be addressed by the ongoing process of policy formulation.

2. The derivation of the potential work packages contained in Appendix 18 identifies the ‘areas of learning’ needed for the selection of practical options with confidence. As discussed in Section 1.3, it is not enough to have performed the work package and answered the questions and key points, it is also necessary to ensure that the information gained becomes an integrated process design which involves relevant stakeholders and the public, so that it forms a credible step towards having ‘sufficient knowledge to proceed with confidence’.

3. In order for any option to be implemented, it must necessarily meet appropriate national and international safety standards. This element of project scope has been delivered by assessing the activities and deliverables necessary to achieve appropriate safety standards, and these appear as elements in the work packages. Unless and until the safety-related work packages of any particular option can be completed with the assurance as mentioned above, then that option could not be selected as part of a credible policy.

4. Safety is a key factor in the selection of any waste management option, and can be thought of as a potential ‘show stopper’ where the safety case cannot be made with sufficient certainty or credibility. Other areas, such as technology, cost, legal restrictions, or political and diplomatic difficulties also provide additional hurdles for the various options, some of which may be insurmountable. However, the UK is not alone in having to find safe yet practicable solutions.

5. As described in Section 1.5, the HLW and Spent Fuel project produced work packages with outline timescales and classification into the broad activity bands (related to performance, design, communication and siting) and level of priority (essential, desirable, supporting). The project did not, however, estimate the effort required or the cost of the work packages. The project team also felt unable to estimate effort and costs, given the breadth and complexity of the work package structure which has been revealed as the project methodology evolved.

6. These HLW and Spent Fuel project work packages are seen in ‘Task 2-3 final Draft research requirements.pdf’ (pages 35-153) as part of that project’s final report. When viewed alongside the INRP ‘Option 05 – Underground Disposal’ work packages, they provide more detail on the technical side, but INRP puts them in the context of a wider examination of radioactive waste policy and the process involved in its development.
7. Experience obtained during the project indicates that pursuing all waste management options in parallel to the same level of detailed consideration would produce a very large and complicated programme. The effort and expertise required cannot be deliverable against the timetable envisaged in MRWS. It must also be considered whether most stakeholders and the general public would view such a programme as an appropriate use of resources.

8. The team would therefore recommend that any process embarked on under MRWS should have the ability to prioritise work packages transparently so as to produce a more manageable overall programme. The work done under the INRP and the team’s background knowledge leads to the view that a proportion of the work packages involve either disproportionate amounts of resources or have limited prospects for a successful outcome.

9. It is therefore possible to envisage a process which conforms to the aims of openness, transparency and inclusiveness espoused by MRWS, and which is likely to legitimately exclude several of the options very early in the process.

10. Such a process might usefully start by identifying those work packages likely to produce, for example, very high costs, inadequate safety assurance, political or diplomatic complexity, or other extreme results. If broad agreement can be gained that the extreme results expected are ‘show stoppers’, then these options can be legitimately excluded. The format given in Appendix 16 might well facilitate this process, and a hypothetical example of such a process is given in Appendix 17. Here, a selection of the 47 generic questions are posed for a hypothetical selection of the 14 waste management options. The results are used to suggest that the options might be reduced substantially early in a transparent MRWS process.

11. Once this prioritisation process is underway, it should be possible to review the potential work packages listed in Appendix 18 which are still relevant, with a view to grouping them and bringing the level of definition and timing appropriate for having the work performed, bearing in mind that many will fall to the implementer of policy over an extended period of time.
11. Comments on Responses to MRWS Consultation Programme

11.1. Introduction

1. This chapter is based on ‘Managing Radioactive Waste Safely: Summary of Responses to the Consultation September 2002 – March 2002’ published by DEFRA and the devolved administrations in July 2002. For clarity the chapter follows the format of this document, briefly summarising the points made and commenting on them from an Information Needs Research Project viewpoint. The project team comments are in *italics*.

11.2. Key Messages emerging

- Most respondents agreed with the review of options. INRP was tasked with reviewing the information needs associated with these options, but was not required to state a position on the appropriateness nor the practicability of options included.

- Many respondents said that the timescale for arriving at a waste management programme should be faster than anticipated.

*INRP comments only that, while recognising the need to arrive at an optimum end-point as soon as is possible, the over-riding need is for the development of an holistic process, and that timescales should be driven by the process rather than vice versa.*

- Others said fixed deadlines should be avoided.

*See INRP comment above.*

- Most respondents who expressed a view supported the creation of a new, independent body. The prevailing view was that the body, not the Government should manage the review.

*INRP comments that the any Body must be part of an holistic process. The Body and the process of setting it up must be transparent and credible to stakeholders if its work is to engender public confidence. This again emphasises the need for an holistic and well thought out process.*

11.3. Summary of Views expressed on particular issues

11.3.1. Programme of Action

Views were invited on a programme of action, including a review of all options for the long term management of solid waste. Around 100 of the 330 respondents commented. A summary of their views was as follows:

- Around a quarter were concerned that timescale was too long.

*INRP comments only that an holistic process is needed, and that timescales should be driven by the process rather than vice versa.*
• Around a quarter thought the timescale about right.

• A smaller number thought it would or should take longer, and that achieving consensus took priority over timetables.

See INRP comment above.

• There was concern that the Government’s proposals to reform the planning system would reduce public debate and involvement, undermining the proposals on radioactive waste.

While this is outside INRP’s strict remit, INRP is of the opinion that the streamlining of planning procedures as it is currently perceived by the public and NGOs mitigates against the ‘with confidence’ aspect of the Government’s programme for managing radioactive waste safely.

• Most respondents welcomed MRWS but some said it should have come sooner.

This is outside INRP’s remit and no comment is offered.

• There is broad support for a full review of all waste management options, though a few said there was already enough information upon which to make decisions, and that further public debate was unnecessary and may cause dangerous delay.

INRP makes no comment on the viability or practicability of the range of options consulted on, but has suggested a methodology whereby it believes that a significant reduction in the number of options being studied can be achieved with relatively little work and expense (see Section 9 and relevant Appendices).

• There is a need for more clarity on what each stage in the process would achieve.

INRP offers a way forward on initial stages in Section 9 and relevant Appendices.

11.3.2. A public debate

Views were invited on how the public could best be involved in the review. Views included:

• The process should actively involve a wide, diverse range of stakeholders.

INRP agrees with this view: stakeholder involvement should be an integral part of part of an holistic MRWS process.

• The process should be open and transparent.

INRP agrees – see comment above.
• The process should provide clear, accurate, balanced information which is disseminated widely.

*INRP agrees – see comment above.*

• The designing of the policy development process should be broken down into clear, distinct and separate stages.

*INRP agrees – see comment above.*

• Most people are not interested in issues relating to radioactive waste until it affects them directly. As things stand at present, this issue remains unresolved but a future process must involve communities which could one day be affected by the need to manage radioactive waste.

*INRP agrees: see comment above. Furthermore, INRP feels that the engagement catchment area must go beyond those communities which could become recipients of a waste repository one day. Engagement should be, as far as is possible, at a national level in order to impress upon the population at large the need for a robust, safe radioactive waste policy and to engage the public at every level in an integrated process to deliver that policy. Limiting engagement processes to those communities likely to be affected by waste repositories in advance of determining the optimum method of managing the waste could create the impression of ‘victim’ communities and could be divisive in respect of the overall objectives of the process.*

• Several respondents have a lack of trust in the nuclear industry, some saying they should be excluded from the debate or that experts must reveal for whom they have worked in the past.

*INRP agrees that participants in the debate should reveal any vested interests they represent: see comment above, which infers the need for transparency, including the current and previous interests of the people concerned.*

• Several said that the Government had not been open or honest up to now and they must act openly, not just talk about it.

*INRP takes no view on the history of radioactive waste management to date, but reiterates the current need for a holistic process which is transparent and involves all relevant stakeholders.*

• Some said consensus was unlikely and it was up to Ministers to take tough decisions.

*INRP agrees that decisions must be made, and even the most transparent and inclusive process will inevitably not satisfy all stakeholders. There will therefore be dissent when a decision is made, but the process should at least enable decisions to be made for transparent reasons and for dissenting views to be openly and explicitly dealt with.*
Other suggestions included:

- The debate should be set in the wider context of nuclear power.

  *INRP believe that radioactive waste management is a problem needing to be solved in its own right, and that this debate should be separated from any ongoing debate on a future role for nuclear power. However, any nuclear power debate must be undertaken with full appreciation of the radioactive waste management issue and should evolve taking into account the state of progress and resolution of the debate.*

- The list of potential sites considered by Nirex up the 1990s should be published.

  *The previous Nirex programme has been discontinued, replaced by a new programme to define the principles governing the choice of future radioactive waste management options. In these circumstances there is no logical reason to publish the list of potential sites which might have been favoured under a now-superseded policy.*

- Government’s role in the process should be minimised and the process should be more independent of Government influence.

  *INRP believes that a transparent process which provides good stakeholder involvement must inevitably be more ‘arm’s length’ from Government than previous programmes.*

11.3.3. The Topics To Cover

About 60 respondents had suggestions about topics to be covered in MRWS. Those frequently made suggestions include:

- The future of nuclear power.

  *INRP makes no comment beyond that made above.*

- Very Low Level Waste (VLLW).

  *INRP agrees that VLLW needs to be included in the process, either within MRWS or by a parallel but co-ordinated action.*

- Siting and location of radioactive waste facilities.

  *INRP agree that siting and location will be key aspects of the MRWS process.*

- Sites considered by Nirex in the past.

  *See above.*

- All waste management options and all potential materials should be examined.
INRP agrees, though the exhaustive study of many permutations of waste material and waste management options would be very resource intensive. INRP have suggested methods whereby this might be achieved with reasonable use of resources (see Section 9 and relevant Appendices)

- All aspects of the costs of waste management should be considered.

INRP agrees.

Other topics mentioned by several respondents were:

- defence, including nuclear disarmament,
- transport of radioactive material,
- future generations and security.

INRP agree that policy must be sensitive to these issues.

11.3.4. Techniques

Around 100 people commented on the techniques used to help reach decisions. All comments reinforce the need for an holistic process, which would consider all these methods.

- One in 6 supported use of internet or IT (although it was said that on-line debates were not always well informed.)
- A similar number supported use of the media as many have no access to the internet.
- A similar number supported the use of citizens’ panels, discussion or focus groups.
- Consensus conferences were suggested by 1 in 10.

2. Other suggestions included:

- Learning from experience from here and abroad.
- Holding public meetings.
- Using local authorities to encourage local debate or spread information.
- Holding face-to-face interviews, telephone surveys, on-line questionnaires.
- Using Agenda 21 groups and sustainable development networks.
- Using schools pack and involvement via the national curriculum.
- Advertising events well, notifications in libraries and using mobile exhibitions/roadshows.

The design of the overall MRWS process and the selection of individual techniques is outside INRP’s remit. INRP strongly believes, however, that such an overall process design must be constructed and that the long-term success or otherwise of the MRWS process depends on it.

11.3.5. Managing The Debate – An Independent Body
Around 140 respondents commented on this topic. 4 in 5 thought a new independent body was needed. 1 in 10 thought no new body was needed. A smaller number thought RWMAC would suffice if its structure and remit was modified.

- A few people thought separate bodies should undertake advisory and research functions.
- Two fifths said one body should combine these functions.
- Funding was commented on by 1 in 5. Just over half thought that funding should be provided by waste producers, the rest believing it should come from Government, or a combination of Government and industry.
- Most said that the new body should manage the review of options rather than just advise the Government. This was also the recommendation from the House of Lords, House of Commons and RWMAC.
- Of the 70 respondents who commented on research, most said it should be directed by the new independent body.

This subject is covered by the INRP view of the need for a holistic process, which would consider all these organisational variants. INRP is convinced that such a process is needed and must be fit for the purpose. However, INRP does not take a view on the detailed design.

11.3.6. Managing The Debate – Nirex

Around 70 responses mentioned Nirex. Comments include:

- A third said Nirex should be made independent of the nuclear industry.
- A quarter said its responsibility should extend to include all radioactive wastes and all options for radioactive waste, not just disposal.
- More Nirex staff should have an environmental background.
- A new independent organisation should be created to manage research benefiting from Nirex’s expertise.
- Nirex or its replacement should be rigorously monitored.
- Nirex has lost its credibility and should be disbanded.
- The HoC recommended a quick decision about the future role of Nirex and the future responsibility for the functions it performs.

This subject is covered by the INRP view of the need for a holistic process, which would consider all these organisational variants. INRP is convinced that such a process is needed and must be fit for the purpose. However, INRP does not take a view on the detailed design.

11.3.7. New nuclear power stations

Around 120 responded on this topic.

- 3 in 10 opposed the building of new reactors: the two prevailing reasons for this opposition were:
  - that it would be wrong to generate more waste when we do not know how to deal with the existing waste legacy and,
- the long term risks outweighed the potential benefit.

- A similar number opposed the continued operation of existing reactors.
- A similar number opposed the reprocessing of spent nuclear fuel.
- Around 1 in 5 opposed the manufacture of MOX fuel.
- More than 1 in 10 said we should invest more money or effort in renewables and efficient use of energy.
- The HoC said a review would need to consider the implications of additional waste arising from the operation of new reactors.

**INRP** believe that radioactive waste management is a problem needing to be solved in its own right, and that this debate should be separated from any ongoing debate on a future role for nuclear power. However, any nuclear power debate must be undertaken with full appreciation of the radioactive waste management issue and should evolve taking into account the state of progress and resolution of the debate.

11.3.8. **Plutonium, uranium and spent nuclear fuel**

Around 150 of the 330 responses mentioned plutonium.

- Three fifths said that some or all separated plutonium should be declared a waste.
- A few - including the HoC EFRA Committee and RWMAC - said the review should reflect the possibility of it needing to be managed as a waste.
- Less than one fifth said that there was no need to declare any plutonium a waste.

Around 80 responses mentioned uranium and spent fuel.

- Around a third said that some or all uranium and/or spent fuel should be declared a waste.
- 1 in 5 said they had potential energy usage, the risks were low and there was no need to declare them a waste.

**INRP** takes no view on what should be declared as waste, but is of the opinion that any policy must be adequately flexible, sensitive and resilient to later changes in waste categories and/or amounts.

11.3.9. **Storage of Wastes**

Around 90 people commented on how waste is or should be stored.

- Around a quarter said waste was not safely stored and major improvements were needed.
- Many said the industry must not make the problem worse by continuing to generate nuclear power and reprocess spent nuclear fuel.
- One in 20 said storage arrangements were safe or standards too high.
- Other frequently made comments included concern at the safety of disposal of low level waste and very low level waste.
• 3 in 10 felt waste should be stored at the site of production.
• 1 in 10 felt underground storage or disposal was the best long term option.
• The House of Lords called for surface waste stores to be made less vulnerable and for some wastes to be moved underground.
• RWMAC made some comments on the proposed LMA but said that for the present, waste policy should be reviewed.

INRP takes the view that whatever future policy is decided, waste treatment in the immediate future should concentrate on reducing risk and hazard by processing waste into forms suitable for medium and long term ‘passive’ storage. These activities should not unreasonably preclude options being considered in the ongoing MRWS policy debate. This raises an immediate need to consider rapidly those options which are being precluded or made less relevant by current waste processing actions. MRWS has offered a process which it believes can achieve this.

11.3.10. Regulation

Views were invited on the regulatory system and whether the environment protection agencies needed new powers to control storage. Around 70-80 people commented.

• 3 in 10 supported extra powers for the agencies.
• 4 in 10 (including RWMAC) did not support extra powers.

INRP takes no view, but believes that regulation must facilitate an holistic view of the safety and practicability of ongoing waste management policy and actions.

11.3.11. Decommissioning

1. Around 100 people commented on this.

• A third were generally satisfied with current arrangements.
• 1 in 10 said all existing nuclear reactors should be shut down immediately and decommissioned in less than 30 years.
• A fairly common view was that waste generators – not taxpayers – should cover the costs of waste management from ‘cradle to grave’.

INRP believes that decommissioning must take place according to programmes which take an holistic view of the safety and practicability of ongoing waste management policy and actions. INRP believes that the determination of decommissioning policy is of major importance to MRWS and will impact the required level of sensitivity, flexibility and resilience of the programme to the scheduling of waste inventories requiring management. INRP further believes that the decision about the time horizon determined for decommissioning – currently held to be circa 100 years by the industry and anything shorter than 30 years by critics – should be resolved speedily to facilitate early accommodation of wastes arising.

11.3.12. Waste substitution

Around 110 people commented on this issue, 90 of whom had a view on whether or not waste substitution should be extended. Of those with a view:
• Slightly over half were in favour of extending waste substitution to include ILW.
• Slightly under half were opposed to waste substitution or had reservations.
• RWMAC saw no obvious reason for changing current Government policy. If there were new circumstances, these should be set out fully and assessed and publicly debated before any change took place.

INRP takes no view, but any future policy development or waste management actions must be resilient to a decision either way until such a decision is made.

11.3.13. Managing spent sealed resources

Views were invited on RWMAC’s proposals for managing spent sealed sources which proposes, inter alia, that all sales of new sources must include provision for future disposal. Around 80 people responded. Of those who did:

• Around three quarters stated general support for RWMAC’s proposals.
• The proposal was specifically welcomed by about a third of respondents.
• The proposal to set up an organisation with responsibility for taking abandoned sealed sources under control was specifically welcomed by about a quarter of respondents.
• A smaller number wished to restrict the use of radioactive sources and urged that RWMAC appoint inspectors to monitor the use of sources.
• A number of respondents urged that the international and European dimensions of the problems were fully examined before action was taken.

INRP takes no view but the long term management of spent sealed sources must be covered by ongoing policy development.

11.3.14. Segregating UK Waste types by half lives

About 80 responses mentioned this.

• Nearly 2 in 5 were broadly in favour of the EU classification system although wished to see additional conditions to its use
• Roughly the same number of respondents were against adopting the EU system on the grounds that it was not realistic nor environmentally viable.
• Roughly 1 in 10 wanted a more complex classification system, taking into account more parameters.
• RWMAC supported further study of increased use of segregation for dealing with future wastes.

INRP believes that the waste classification system should be kept under review as the MRWS strategy, and in particular its selection of options, proceeds.

11.4. (Annex 3) Response from RWMAC

11.4.1. Introduction
RWMAC welcomes MRWS as an important step towards formulating policy for long
term management of waste. The timeframe for formulating this policy is envisaged as
5 years. RWMAC believes that policy guidance is needed for the interim period to
assist those who use radioactive materials; to guide the work of the regulators so that
the activities of the Liabilities Management Authority (LMA) can be directed
effectively. There is a need for all policy elements to fit together in a holistic way.
For example, the principles need to be clear and consistent and apply to all sites
(nuclear and non nuclear) that manage radioactive waste. All elements should have
been exposed to public debate and endorsement.

INRP agrees.

11.4.2. The Policy Formulation Process

RWMAC published advice to the Government in September 2001 on the overall
process by which policy for the long-term management of radioactive waste should be
decided. The committee stands by its advice and is pleased that MRWS appears to
endorse the key guiding principles. Other comments:

- The process for deciding future policy should be a measured one and will take
time and should not be rushed although this should not be used as an excuse
for procrastination and a carefully scheduled programme should be
determined.
- ‘Do nothing’ should be included in the list of options so its full implications
  can be appraised.

INRP did not cover the ‘do nothing’ option.

- All management options should be evaluated against an agreed set of criteria
  which reflect public concern and the range of risks.
- Ordering of stages should be clearly defined at the start so that the choice of
  policy can be seen to have emerged logically.
- Before identifying specific locations for new facilities, there is a need to
  define how the process for deciding site selection is to be constructed. The
  process should stop short of identifying sites. An objective evaluation of
  options should not be influenced by local, site-specific questions, although
  consideration of generic siting issues is necessary in order to engage with the
  public most affected by the policy.
- RWMAC believes that the MRWS 2007 target for setting out the means of
  implementation of the preferred management strategy is ambitious but needs
  to be met.

INRP did not comment or come to views on the detailed attributes of a process,
merely that it must be holistic and involve stakeholders to the maximum feasible
extent.

11.4.3. The overseeing body
RWMAC is convinced of the need for an independent body with the duty to design and oversee the overall process of formulating policy. It believes appointments to the body should be made on an ‘ad hominem’ as opposed to representative basis, and that it should be established no later than the end of 2002. RWMAC suggests that the relationship of the body to the Government should be such that decisions can be ‘banked’ stage by stage, perhaps involving a parliamentary debate at each stage of the process, to avoid the body spending years and lots of money making decisions that are discarded by Government.

_INRP did not comment or come to views on the detailed attributes of a process, merely that it must be holistic and involve stakeholders to the maximum feasible extent._

11.4.4. The Liabilities Management Authority

RWMAC believes:

- Development of the LMA needs to reflect the nature of the debate on policy formulation for the long term management of solid radioactive waste, which MRWS has initiated.
- LMA will need to begin its work in the interim period before policy is decided and certainly before policy itself comes to be implemented.
- The LMA must be given clear direction.

_INRP took no views on the LMA apart from the fact that the process involved must be strongly linked to MRWS if an overall holistic programme is to result._

11.4.5. Policy for the interim period

1. It is unclear to those outside Government which parts of the 1995 Cm 2129 policy are extant and those parts which have been superseded by new developments (such as the 1998 OSPAR Sintra agreement) and initiatives (such as MRWS and the LMA). Government must take steps to clarify which parts of Cm 2129 are extant

2. RWMAC believes that interim policy guidance should address issues including:

- The decommissioning policy towards which the LMA’s work should be striving.
- Standards and objectives to be applied to the conditioning, packaging and storage of solid waste.
- Government policy for treating waste for passively safe storage.
- The need for confidence in the ultimate long term management agreements for waste.
- The need to deal with any spent fuel, plutonium and uranium declared as a waste.
- Government policy for control of radioactive discharges.
- Standards to be applied to nuclear site remediation and clean up of contaminated land.
• The need to make progress with the retrieval, conditioning and packaging of historic wastes.
• Clarify some of the terminology used. If the public are to be involved, use of consistent and easily understandable language should be used.

INRP views on these matters are covered under the relevant headings of the main report.

11.4.6. Regulation of storage on licensed nuclear sites

RWMAC believes:

• There is a case for enabling the Environment Agency (EA) and Scottish Environmental Protection Agency (SEPA) to provide additional ‘regulatory assurance’ in relation to the environmental impact of storage and management of waste produced on nuclear sites.
• On the whole, RWMAC is not in favour of the EA’s suggestion for a new statutory power over the storage of waste.
• Other approaches to enhancing the role of the environment agencies should be examined. For example, one of the three stages in the Nirex ‘letter of comfort’ process should perhaps be subject to endorsement by the appropriate EA, or perhaps a new statutory role for the agencies should be developed. Such proposals should be subject to early appraisal by the Government.
• Disagreements and disputes in relation to the regulation of radioactive wastes on nuclear sites could be resolved more readily if key stakeholders were operating within a clear and adequate policy context, while embracing a ‘common purpose’ approach.

INRP views on these matters are covered under the relevant headings of the main report.

11.4.7. Segregation of UK waste categories by half-life

• RWMAC has occasionally considered categorisation for solid wastes. The categorisation system needs to reflect a balance between operational/technical and public information needs.
• Retrospective separation by half life is a very difficult, if not impossible task. It could add to the time and cost of dealing with the waste, and an increased worker dose.
• RWMAC believes the possibility of dealing with future waste through the use of increased segregation by half life worthy of further study.

INRP believes that the waste classification system should be kept under review as the MRWS strategy, and in particular its selection of options, proceeds.
11.4.8. RWMAC’s proposals for the Management of Spent Sealed Radioactive Sources (SSRSs)

RWMAC comments:

- The LMA’s remit does not currently include historic waste liabilities in the form of SSRSs from educational and medical establishments but RWMAC recommends that such sources be included in the remit as they are, in effect, Government owned.
- RWMAC welcomes initiatives by the EA to explore in detail practical issues relating to the management and disposal of sealed radioactive sources. It sees a need for a robust system to be developed to deal with sources to be purchased in future as well as arrangements for ‘orphan’ sources.

*INRP takes no view, but the long-term management of spent sealed sources must be covered by ongoing policy development.*

11.4.9. Waste Substitution

RWMAC says:

- RWMAC commented on the handling of overseas radioactive materials in its 1999 advice to Ministers. It stated there was a lack of transparency concerning holdings of overseas material within the UK and the proposed schedule for their return, encouraging criticism that the UK is in effect a nuclear dumping ground. Therefore RWMAC sees transparency and monitoring of declared policy and intent for return of the overseas material to be important.
- The Cm 2191 discussion of substitution noted that a more vigorous environmental appraisal of the characteristics of an ILW disposal facility itself would be needed to reduce other uncertainties concerning the likely impact on the UK.
- Cm 2919 expressed the view that such considerations were of continuing relevance to the possibility of ILW substitution arrangements, since no UK disposal facility was available.
- RWMAC sees no obvious reason at present for revising UK policy on substitution. On the face of it, the need for policy change could only arise from new circumstances.
- RWMAC believes that BNFL should regularly update its plans for return of reprocessing wastes to its overseas customers and report progress on their return. The actual return of wastes against such forward planning should serve as an indicator of BNFL’s performance.

*INRP takes no view, but any future policy development or waste management actions must be resilient to a decision either way until such a decision is made.*
11.4.10 The General Approach To Decommissioning

RWMAC supports:

- A ‘case by case’ approach to decommissioning.
- Provision for the early involvement of the environment agencies and Nirex, together with HSE and local councils and communities, in formulating individual site decommissioning strategies.

Other comments:

- For decommissioning strategies to be formulated effectively, other elements of Government radioactive waste policy need to be clear. For example, standards and lifetimes that need to be adopted for waste conditioning, packaging and storage; concept of ‘passivity’; how the terms of the OSPAR-Sintra agreement are to be applied in respect of decommissioning; standards for remediation of radioactively contaminated land.
- There needs to be a Government statement on decommissioning, including the extent to which it is prepared to see parts of existing sites shut off or access controlled for long periods – possibly 100 years + - in the case of the ‘safestore’ concept described in Cm 2919.

INRP takes no view, but believes that decommissioning must take place according to programmes which take a holistic view of the safety and practicability of ongoing waste management policy and actions.

11.4.11. Plutonium and Uranium

RWMAC comments:

- At least a proportion of the UK’s current stocks will need to be declared a waste at some future point.
- There must be a challenging look at each component of stocks to decide which should be declared a waste in the shorter term.
- Gaps in knowledge exist concerning the way in which plutonium and uranium should be treated for longer term interim storage or eventual disposal as wastes. There should be wider consideration of whether principles developed by the Nuclear Installations Inspectorate (NII) /Health and Safety Executive (HSE) for passively safe storage should be applied similarly to plutonium and uranium stocks.
- Events of September 11th 2001 mean additional security measures need to be taken into account for the way that plutonium and uranium are conditioned, packaged and stored.
- Potential plutonium waste forms should be included in the process of evaluating long-term management options for solid radioactive waste against common criteria as part of the formulation of policy.
- Work should be initiated to identify plutonium material and storage forms that could be considered to be sufficiently passively safe, and put in place a system
of ensuring that these are compatible with their long term waste management. The need for similar work in relation to potential uranium waste also needs to be addressed.

*INRP takes no view on what should be declared as waste, but is convinced that any policy must be seen to have adequate resilience to later changes in waste categories and/or amounts.*
Section 12. Conclusions

1. The project has been driven by the needs of the policy development programme introduced by the publication of MRWS. It seeks to identify the range of radioactive waste management options, and the detailed information required, by the UK Government, in order to select with confidence practical management options for solid long-lived radioactive wastes. The project was conducted for DEFRA by WECL and was peer reviewed and guided by an extended group of experts/stakeholders appointed as a Steering Group.

2. The study was intended to identify any lack of the information necessary to enable the options to be progressed to a decision, and also to estimate the staff and time resources that this would require. This did not prove to be possible. Another requirement was to assess ‘the importance of what will not be known and may remain unknown’, which can only be evaluated against the background of what is meant by ‘with confidence’. The issue of confidence alone will determine the importance of uncertainty and will be affected by the process by which information is integrated into the ongoing policy development process. The level of uncertainty which would be tolerable was therefore not explicitly determined. The project commenced with a literature survey and information gathering phase, followed by a general review of the long term waste management implications of Government Policy and Principles, Law, Treaties and Obligations, Science and Technology, and Public Acceptability. Subsequently, the project examined the attributes and information needs of individual waste management options.

3. During the initial phase, 14 waste management options were identified and reviewed for five UK waste or potential waste types. In the second phase a methodology was developed to define the information needs of these management options. This was based on the similar task performed in the 1997-99 project ‘An R&D Strategy for the Disposal of High-Level Waste and Spent Fuel’. This project had identified the information needs for the geological disposal of a waste and a potential waste type (HLW and Spent Fuel), together with some consideration of plutonium, uranium and ILW. The project identified 60 work packages to meet the policy and technical milestones of this scenario, i.e. to the point of closure of the repository, a process of 40 years or more.

4. For the greater range of possibilities covered under the INRP, a set of 47 Generic Questions was assembled which were peer reviewed by the Steering Group. The questions included, either directly or indirectly, all the criteria suggested by the RWMAC in their recent review. These 47 questions were answered for all 14 options, and this exercise provided an initial scoping of the extent and complexity of the information which would be needed to take forward the options.

5. As a second stage, key points and questions derived from the general topic reviews described in paragraph 2 above were fed into the analysis. These could be expected to cover a similar field to the 47 Generic Questions but having been generated later in the process provided a further insight into information needs and further reduced any subjectivity by the authors. This complemented the next stage: the generation of information needs ‘Work Packages’.
6. All the answers to the Generic Questions, plus the key points and questions generated from the general topic reviews were allocated to the relevant HLW and Spent Fuel Project work packages. Some INRP questions and attributes did not map onto these work packages and new work packages were developed to satisfy these. This led to the complete work package attribute listing for all options and to the identification of 630 potential work packages. The word ‘potential’ is important as, when taking the MRWS process forward, it should be possible to remove some options, and hence work packages, from consideration at an early stage (see below).

7. The project has not considered the possibilities of different waste management options being adopted for the various waste streams, as the number of permutations becomes unwieldy. This added complication must, however, be addressed by the ongoing process of policy formulation.

8. The derivation of the INRP work packages identifies the ‘areas of learning’ needed for the selection of practical options with confidence. It is not enough to have performed the work package and answered the questions and key points, it is also necessary to ensure that the information gained becomes part of an integrated process design which involves relevant stakeholders and the public, so that it becomes a credible step towards having ‘sufficient knowledge to proceed with confidence’.

9 For any option to be implemented, it must necessarily meet appropriate national and international safety and legal requirements. The activities necessary to achieve this are contained in the work packages. The current Government policy review may only need to establish that on balance an option or combination of options is clearly ahead of other options/combinations and that there is a strong enough probability that it will meet the necessary standards to proceed with confidence. This is because all the waste- and site-specific circumstances cannot be known in advance of a specific scheme being defined. Much further work on meeting all appropriate requirements must then be done while the chosen policy is being implemented, possibly over a period of 25 years or more.

10. Safety is a key factor in the selection of any waste management option, and can be thought of as a potential ‘show stopper’ where the generic safety case cannot be made with sufficient certainty or credibility. Other areas, such as technology, cost, legal restrictions, or political and diplomatic difficulties also provide additional hurdles for the various options, some of which may be insurmountable.

11. While the HLW and Spent Fuel project described work packages with outline timescales and classification into broad activity bands, it did not estimate the effort required or the cost of the work packages. The project team also felt unable to estimate effort and costs, given the breadth and complexity of the work package structure which has been revealed as the project methodology evolved.

12. Experience obtained during the project indicates that pursuing all waste management options in parallel to the same level of detailed consideration would not produce a manageable programme. The effort and expertise required cannot be deliverable against the programme envisaged in MRWS. It must also be considered whether most stakeholders and the general public would view such a programme as an appropriate use of resources.
13. The project team would therefore recommend that any process embarked on under MRWS should have the ability to transparently prioritise work packages to produce a more manageable overall programme.

14. It is possible to envisage a process which conforms to the aims of openness, transparency and inclusiveness espoused by MRWS, and which is likely to legitimately exclude several of the options very early in the process.

15. Such a process might usefully start by identifying those work packages likely to produce, for example, very high costs, inadequate safety assurance, political or diplomatic complexity, or other extreme results. The work done under the INRP and the team’s background knowledge leads to the view that a proportion of the potential work packages involve either disproportionate amounts of resources or have limited prospects for a successful outcome. If broad agreement can be gained that the extreme results expected are ‘show stoppers’, then these options can be legitimately excluded. Examples have been developed of how this might be done.

16. Once this prioritisation process is underway, it should then be possible to review the INRP work packages which are still relevant, with a view to grouping them and bringing the level of definition and timing appropriate to having the work performed. Many will fall to the chosen implementer of policy to complete over an extended period of time.

Additional Commentary

17. During the period of debate and policy formation, elements of the previous waste policy are still directing current activities. ILW is being conditioned against a Nirex letter of comfort system aimed at geological disposal, while the NII are considering an interim storage period of up to 150 years. There is therefore a need to ascertain whether this timeframe for interim storage is an acceptable background to the process of choosing ‘practical management options for solid long-lived radioactive wastes.

In particular:

- Is an emphasis on moving as soon as is reasonably possible to passive, safe, monitorable and retrievable interim storage a suitable policy for untreated waste?
- Is an overall period of interim storage of 100 - 150 years a suitable planning basis for radioactive waste and material being placed in storage now?
- Should the preserving the possibility of eventual deep geological disposal still effectively define the specification for ILW to be treated for storage or could a more general specification covering a number of options be found?

18. These questions need to be answered well in advance of the policy envisaged by MRWS being defined, and represent an urgent area for policy decision.

19. Other policy and regulatory developments will interact with the MRWS process. In addition to the announced implementation of a Liabilities Management Authority, there are a number of key regulatory consultations and outstanding policy issues which will impact upon the technical implementation and therefore the public
acceptability of the various options outlined in the INRP evaluation. There should therefore be a work stream to determine the interaction between these various consultations and any additional information requirements that could emerge.
13. List of Acronyms and Glossary

13.1 List of Acronyms

AGR: Advanced Gas Cooled Reactor
BGS: British Geological Survey
BNFL: British Nuclear Fuels plc
CDZ: Chemically Disturbed Zone
DEFRA: Department for Environment, Food and Rural Affairs
DETR: Department of Environment, Transport and the Regions (now DEFRA)
EBS: Engineered Barrier System
EA: Environment Agency
EDZ: Excavation Disturbed Zone
HLW: High Level Waste
ILW: Intermediate Level Waste
MOX: Mixed Oxide Fuel
NEA: Nuclear Energy Agency of the Organisation for Economic Co-operation and Development
OECD: Organisation for Economic Co-operation and Development
PA: Performance Assessment
PWR: Pressurised Water Reactor
RCF: Rock Characterisation Facility
RDP: Repository Development Programme
RWMAC: Radioactive Waste Management Advisory Committee
SKB: Swedish Nuclear Waste Management Company
TCHM: Thermo-Chemical-Hydro-Mechanical
UKAEA: United Kingdom Atomic Energy Authority
URL: Underground Research Laboratory
WVP: Waste Vitrification Plant

13.2 Glossary

Actinide: A heavy element, of the ‘actinide series’ of the Periodic Table, which includes uranium, plutonium and americium.

Activation product: An element which has become radioactive as a result of bombardment by neutrons. Activated elements are found in the components of nuclear reactors.

Alpha Radioactivity: Radioactivity arising from radionuclide decay involving the production of alpha particles, which consist of two protons and two neutrons.

Argillaceous Rocks: Rocks that are rich in clay minerals.

Backfill: Material placed in an excavation or between containers to provide mechanical stability by reducing voidage, and possibly to reduce groundwater flow and provide chemical conditioning.

Barriers: Components of the repository system that reduce the rate at which radionuclides from the waste can be mobilised and reach the human environment.

Becquerel (Bq): The unit of radioactivity, equivalent to the decay of one radioactive atom per second. A Terabecquerel is 10 to the power of 12 (a million million) Becquerels.

Beta Radioactivity: Radioactivity arising from radionuclide decay involving the production of beta particles, which are electrons (or positrons).
**Biosphere:** Regions of the Earth able to support life. This includes the land surface, the oceans (hydrosphere) and the atmosphere. In repository performance assessments the biosphere is generally taken to be those parts of the environment accessible to human beings.

**Borosilicate Glass:** The glass matrix that incorporates high level waste radionuclides in its chemical structure to form a solid waste material.

**Buffer:** A material placed in a repository around waste containers to protect them from mechanical damage and groundwater flow.

**Canister:** The outer containment of a waste package intended for emplacement in a repository: normally a metal, selected for its long-term corrosion properties. Sometimes termed overpack. See also, container.

**Colloid:** A particle with dimensions between one nanometre ($10^{-9}$) and one micrometre ($10^{-6}$).

**Conceptual model:** A description of a system and the key processes that occur within it. This is used as the basis for establishing a mathematical model of the system.

**Conditioning:** The process of converting a waste material into a solid, stable waste form suitable for storage or disposal.

**Container:** The vessel (usually metallic) in which a waste is initially packaged for storage and transport to a repository. It may then be placed in a final disposal canister, chosen for its long-term corrosion properties.

**Criticality:** The state when an accumulation of spontaneously fissile radioelements reaches a concentration such that a self-sustaining nuclear fission reaction can take place. This can produce large quantities of energy.

**Decommissioning:** A generic term to cover all of the procedures undertaken once a nuclear installation has ceased to operate. It covers processes such as defuelling reactors, cleaning and making safe installations (which could include a long period of safe storage on site), dismantling, removal work and waste conditioning prior to storage or disposal.

**Depleted Uranium:** Uranium depleted in the fissile radionuclide, U235, and remaining after the process of enrichment.

**Diffusion:** The process by which a material spreads out in a fluid (gas or liquid) as a result of molecular motions.

**Disturbed Zone (Excavation) - EDZ, Disturbed Zone (Chemically) - CDZ:** A region of rock that has been altered as a result of underground construction or the emplacement of waste or engineered barriers. The changes may be physical and/or chemical and would usually be adjacent to the facility or the access route.

**Drift:** An inclined access tunnel to an underground facility.

**Engineered Barrier System:** A component of the repository or waste packaging or conditioning that delays or prevents radionuclide migration from the repository system.

**Enrichment:** The process by which the proportion of the fissile isotope U235 in uranium is increased to allow its use in modern reactor system.

**Fission:** Nuclear fission is the process by which a heavy atom (such as uranium) splits into two or more smaller fragments. This can occur spontaneously for some radionuclides, or may be induced by bombardment with neutrons.

**Fission product:** A nuclide produced either by fission or by the radioactive decay of a radionuclide formed by fission.

**Gamma Radioactivity:** Radioactivity arising from radionuclide decay involving the production of gamma rays: electromagnetic radiation of the same nature as X-rays, but with shorter wavelengths.
**Geosphere:** In general usage this is synonymous with the lithosphere; the outer layer of the earth. In repository performance assessments it is used to refer to the rocks between the repository and the biosphere.

**Geochemistry:** The study of the chemical composition of the Earth’s crust and changes which take place within it.

**Geotechnical:** Relating to the engineering properties of a rock.

**Grout:** In radioactive waste management, a cement-based material used to immobilise radioactive waste in a container. In engineering, the use of a thin fluid mortar for filling fractures and reducing water flow through the fractures.

**Half-life:** The time taken for half the atoms of a particular radionuclide to undergo radioactive decay(s).

**High-level waste (HLW):** The highly radioactive waste which is separated during the first solvent extraction cycle of spent fuel reprocessing and, in the UK, subsequently converted to a solid glass waste form by the process of vitrification. It has a high thermal power. A high level of shielding and heat dissipation is required during storage and disposal.

**Hydrogeology:** The study of the geological factors relating to the Earth’s water.

**Intermediate-Level Waste (ILW):** Radioactive waste of activity and heat output lower than high-level waste but higher than low-level waste. Most UK ILW requires shielding. Heat production is usually less than HLW, but it may require provision for heat dissipation during storage or disposal.

**Isotope:** Atoms of the same element with different masses are referred to as isotopes of that element. As an example, one isotope of oxygen is O18, which has 18 protons and neutrons in the nucleus of the atom (10 neutrons and 8 protons). This isotope has 2 extra neutrons compared with the most common isotope of oxygen, O16 which has 16 neutrons and protons (8 of each). Similarly, Cl36 is an isotope of chlorine which has 36 neutrons and protons in its nucleus, one extra neutron compared with the more common Cl35.

**Low-level waste (LLW):** Radioactive waste containing less than 4 million Bq per kg of alpha radioactivity and 12 million Bq per kg of beta and gamma radioactivity. Does not require shielding during normal handling and transport.

**Magnox:** A magnesium alloy used for sheathing uranium fuel elements. This alloy gave its name to the first generation of UK gas-cooled nuclear reactors.

**Mathematical model (or simply model):** A description of the behaviour of a system using mathematical equations. Sometimes referred to as a numerical model.

**Mixed Oxide Fuel (MOX):** A nuclear fuel made up of a mixture of uranium and plutonium oxides.

**Multibarrier Concept:** Repository concept whereby a number of barriers (typically, solid waste form, container, buffer and surrounding rock) act in concert to contain the wastes and ensure that any radionuclides released from the waste return to the biosphere in concentrations which do not pose unacceptable risks.

**Natural Analogue:** An occurrence in nature of a material or process that is similar to those that are to be found in a waste repository. Natural analogues are studied principally because they offer the potential to evaluate processes which have been active over much longer times scales than it is possible to simulate in the laboratory.

**Overpack:** See canister.

**Palaeohydrogeology:** The study of the evolution of rock-groundwater systems through long periods in the past. This normally involves measurements of the
hydrochemistry and isotopic differences of groundwater bodies, as well as data on rock mineralogy.

**Performance Assessment**: The process in which the future evolution of all or part of a disposal system (a repository and its surrounding geosphere and biosphere) are analysed to evaluate behaviour or radiological safety.

**Permeability**: The capacity of a medium to transmit a fluid.

**Policy Maker**: Government Department responsible for setting radioactive waste management policy.

**Porosity**: The fraction of a medium that is pore space.

**Radioelement**: An element (such as plutonium) which is radioactive.

**Radionuclide**: A nucleus of an atom which is radioactive.

**Reprocessing**: The chemical treatment of spent fuel, initially by dissolution in nitric acid, to separate and remove uranium and plutonium. The residue of fission products and other actinide elements forms high level waste.

**Retrievability**: Generally applied to the capability, at some future time, to remove waste from an underground storage or disposal facility, implying that disposal is not irreversible.

**Rock Characterisation Facility (RCF)**: An underground excavation, comprising shafts, drifts and galleries, used to gain access to the rock at depth, at a potential repository site, so that it can be studied in more detail than by investigations from boreholes. Distinguished from Underground Research Laboratories by being at the site of an intended repository.

**Regulator**: An agency formally responsible for regulating and approving waste management and disposal practices.

**Safeguards (Nuclear)**: The system of monitoring and security measures adopted nationally and internationally to ensure that material that has the potential to be made into nuclear weapons does not fall into unauthorised hands.

**Shielding**: In radioactive waste management, materials placed between a source of radiation and people in order to reduce the radiation dose received. Waste packages are referred to as shielded if they have their own shielding (such as concrete), or unshielded if not.

**Site Characterisation**: The investigation of the geological and environmental properties of a potential repository site by observations from the surface, from boreholes and from the underground.

**Sorption**: The process by which materials in a liquid phase are transferred to a solid phase (generally radionuclides being transferred from groundwater to rock or soil).

**Spent Fuel**: Uranium or uranium oxide fuel elements that have been removed from a nuclear reactor at the end of their useful lives. Spent fuel builds up a substantial content of fission products and actinide elements as it is ‘burned’ in the reactor. These progressively reduce the efficiency of the fuel, until it has to be replaced.

**Spent Fuel Standard**: Term used in the USA to describe the addition of ‘extra’ radioactivity to a plutonium waste form to make the waste as radioactive as the original spent fuel from which the plutonium was removed. This is done to make illicit diversion of plutonium more difficult, thus helping to ensure that nuclear safeguards are maintained.

**Terabecquerel**: See becquerel.

**Thermo-Chemical-Hydro-Mechanical**: the combined effects of heat, chemical, groundwater and mechanical aspects in and around a repository.
**Transmutation:** Process by which radionuclides are bombarded with neutrons (either in a nuclear reactor or a particle accelerator) and are converted into shorter-lived or stable nuclides.

**Transuranic:** An element in the Periodic Table which is heavier than uranium (includes elements such as plutonium, americium and curium).

**Underground Research Laboratory (URL):** An underground research facility in shafts and galleries in the rock, used to carry out tests and experiments to provide generic information on a typical geological environment. URLs are usually not located at specific repository sites and are to be distinguished from Rock Characterisation Facilities.

**Vitrification:** Process in which liquid HLW is calcined to dryness, mixed with inert chemicals, melted and cooled to form a stable, solid glassy waste product.

**Waste Form:** Solidified, conditioned waste material in a state considered suitable for packaging for long-term storage and disposal.

**Waste Producer:** Any organisation that produces, and has the responsibility for managing, radioactive waste.
Section 14. Bibliography

14.1 Methodology

1. The way the bibliography was developed was determined by the basic project methodology (see Section 1.6 and Appendix 2). The initial ‘horizontal’ work packages commenced with a review of high level summary papers in this area and these provided further more detailed references which were progressively consulted. It was obvious from the start that the assimilation, or even the listing, of the totality of publications in the filed of radioactive waste disposal was not a practical proposition. The project team therefore devised a classification system which covered all aspects of all the waste management options described in Section 3, and carried on the literature review until it was judged that the whole field had been covered to an adequate level of detail.

2. This led to the bibliography list given in Appendix 19 of this report. In this list the initial numerical identifier gives the location of the individual reference in the INRP Nuclear Waste Management Database, which, available as an Access or Excel database, allows the references to be searched on the basis of the categorization scheme given below.

3. The project scope was so wide that its methodology precluded the exhaustive attribution of references in the main text. Crucial references have been given as footnotes, however, and are designated either in full or by their unique identifier in the INRP Nuclear Waste Management Database, and in Appendix 19.

14.2 Bibliography Categorisation

Section A. Long Term Waste Management Options

A1 Above Ground Storage
A2 International Above Ground Storage
A3 Underground Storage
A4 International Underground Storage
A5 Underground Disposal
A6 International Underground Disposal
A7 Direct Injection
A8 Disposal at Sea
A9 Sub-Seabed Disposal
A10 Disposal in Ice Sheets
A11 Disposal in Subduction Zones
A12 Partition and Transmutation
A13 Disposal in Space (including solar disposal)
A14 Dilute and Disperse

Section B. Laws, Treaties and Obligations

B1. International treaties and obligations
B2. National/EU legislation
Section C. Principles and Government Policy

C1. Government Policy
C2. Principles
C3 UK Regulation (new)

Section D. Scientific and Technical Aspects

D1. International Experience
D2. Safety and Security
D3. UK Experience
D4. Areas and Degree of Controversy
D5. Quality Assurance
D6. Transport
D7. Cost
D8. Risk and Hazard
D9 Decommissioning
D10 Monitoring and Retrieval
D11 Siting

Section E. Public Acceptability

E4. Scientific Community
E5. Likely NGO Attitudes
E6. Comparison with Alternatives
E7. Other Opinion Formers e.g. MPs
15. List of Appendices

1. Accepted project programme
2. Project methodology and structure
3. Information Needs Research Project Steering Group Membership
4. Wilkinson Environmental Consulting Ltd – INRP Team
5. Radiation dose and risk
6. International and European Law
7. National Laws
8. Methodology for deriving overall research scope
9. Applicability of HLW-Spent Fuel Project work packages to INRP options
10. Detailed answers to 47 generic questions – all waste management options
11. Key points from the spent fuel management options described in Section 3
12. Key questions from legal assessment
13. Key questions from public acceptability assessment
14. Key questions from Environmental Interest Group perspective
15. Work package attributes for spent fuel management options
16. Complete work package listing
17. Example option examination
18. Work package outline definitions