The Environment Council

BNFL NATIONAL STAKEHOLDER DIALOGUE

PLUTONIUM WORKING GROUP

March 2003

FINAL REPORT

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Produced by The Environment Council

March 2003

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Foreword to Final Report of the Plutonium Working Group in the BNFL National Dialogue

Aim of the BNFL National Dialogue
The BNFL National Dialogue involves a wide range of organisations and individuals interested in or concerned about nuclear issues. Its aim *is to inform BNFL's decision-making process about the improvement of their environmental performance in the context of their overall development.*

The dialogue is open to national organisations and regional groups as well as well as expert and specialist concerns. If you believe you are affected by the issues, think you can contribute or wish to participate (or if you know of anyone else who should be involved) then please contact The Environment Council on 020 7632 0117. (Criteria for Membership are attached).

Guidance on Interpreting the Final Report

The report must be read carefully. The working group have been very careful to outline where they agree and disagree and they have tried to be as explicit as possible.

Participation (by organisation or individuals) in either the overall dialogue or the working groups must not be taken as an indication of support or disagreement with the dialogue itself, its outputs or BNFL's activities.

Any quotes from the reports used in talks, articles, consultation papers and/or other documents published on paper or electronically must be put within the context given within the relevant section of the working group's report. The Environment Council strongly advise those considering quoting from the reports to forward their proposed text for review to Rhuari Bennett (e-mail: rhuarib@envcouncil.org.uk)

The role of the convenor
The convenor of the dialogue is The Environment Council, an independent UK charity. The Environment Council is responsible for designing and facilitating each stage in the dialogue, and provides relevant support, like issuing invitations and booking venues.

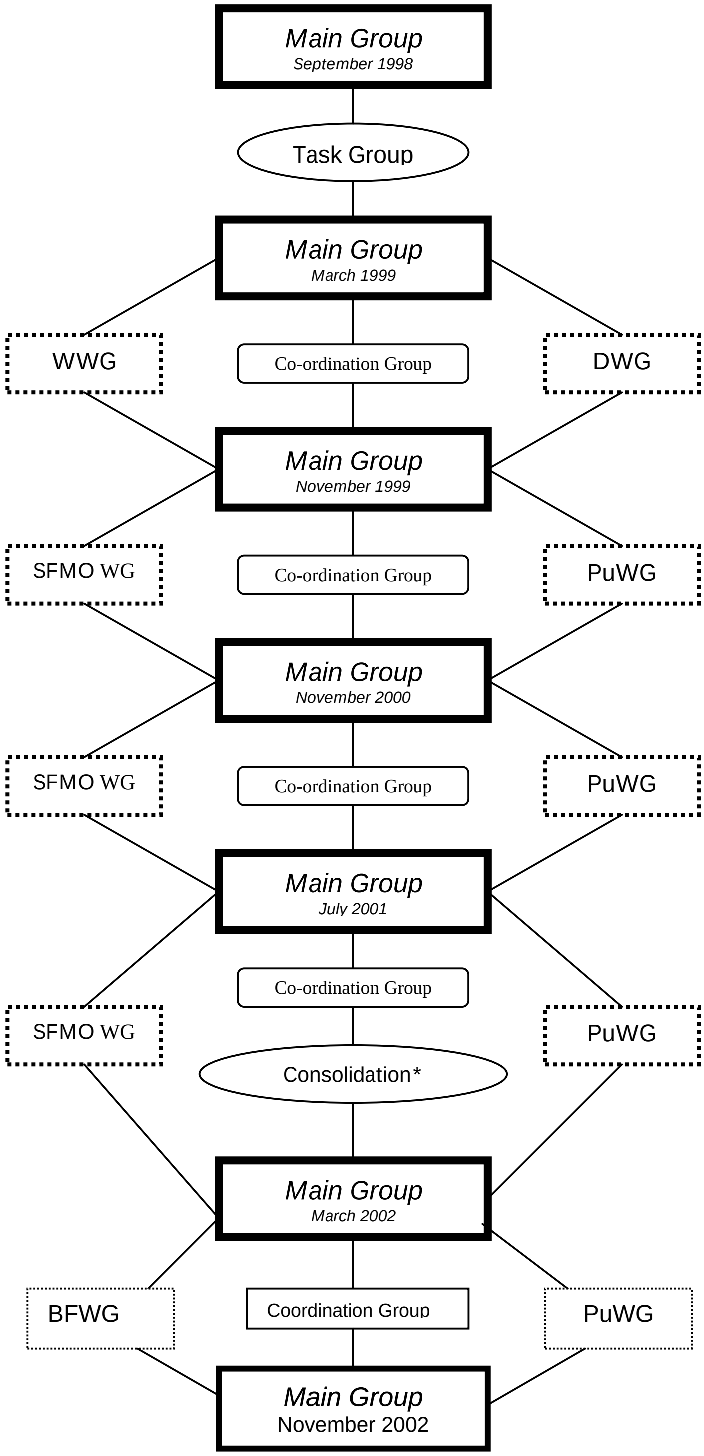
The Environment Council is not responsible for any issue discussed in the dialogue, and holds no formal position on any of the substantive issues that are or might be considered. It is for the participants to decide what issues are raised, how they might be addressed and how any observations, conclusions and recommendations might be recorded and communicated.

The website of The Environment Council, www.the-environment-council.org.uk displays a full history and evolution of the Dialogue, as well as all of the reports that have been produced from the process.

The Environment Council, March 2003

History of the BNFL National Stakeholder Dialogue

The diagram below outlines the inception and evolution of the BNFL National Stakeholder Dialogue process. A more detailed history and explanation of each of the groups, together with the reports produced and lists of group members is available on The Environment Council website www.the-environment-council.org.uk



Key:

WWG	Waste Working Group
DWG	Discharges Working Group
BFWG	Business Futures Working Group
PuWG	Plutonium Working Group
SFMO WG	Spent Fuel Management Options Working Group

***Consolidation**: this was a phase of work including:

- Reconvening of:
  - Magnox Task Group
  - WWG & DWG
  - Transport Task Group
- LLR Task Group
- BFWG startup
- Evidence gathering

Notes:

- The Coordination Group is responsible for providing guidance on linkages and continuity between groups, as well as identifying problems and potential 'wobbles'.
- "Socio-Economic" and "Transport" issues were discussed throughout the process
- Contact Rhuari Bennett for more information on 020 7632 0134, rhuarib@envcouncil.org.uk

The Environment Council

Attachment

BNFL NATIONAL STAKEHOLDER DIALOGUE

GROUNDRULES

6th DRAFT

17th November 2000

SELECTION CRITERIA FOR WORKING GROUPS

One output from Main Group meetings of stakeholders in the BNFL National Stakeholder Dialogue will be the formation of Working Groups. These Working Groups will carry forward more detailed elements of the work and report back to the next Main Group meeting.

Experience of Working Group meetings demonstrates that around 15 members provides a cohesive, practical and effective group. If there are more volunteers than places, a number of criteria will inform the Co-ordinating Group's selection from the volunteers.

People participating in the Working Groups must:

- represent a particular constituency and/or have relevant experience or expertise relevant to the Working Group;
- have been inducted into the process and style of working;
- accept and conform to the ground rules, and participate in their review and development;
- develop, observe and work in a co-operative spirit in the Working Group, while respecting that profound differences of opinion may exist;
- be a competent and collaborative negotiator (rather than a positional/competitive bargainer);
- be available for the full series of Working Group meetings (which may be 1 to 1½ days every month or 6 weeks) and Main Group meetings;
- be willing to undertake work between meetings, signposting or providing papers and reviewing information within the timescales agreed within the Working Group (this may be up to 1 week's work per month).

In addition to the above, the overall group profile will also influence Co-ordinating Group's choice. Ideally, each working group will need to contain representatives from the following sectors

- communities;
- company;
- customers;
- environmental NGOs;
- other NGOs;
- government;
- regulators;
- workforce;

and will need to be balanced in terms of the necessary skills.

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Disclaimers to the Final Report of the Plutonium Working Group in the BNFL National Dialogue

Plutonium Working Group:

The participation of some of the Plutonium Working Group members in the discussions, and agreement with the Plutonium Working Group's recommendations, should not be taken as an endorsement of further plutonium separation or the production and use of MOX as fuel or for any other purpose, including immobilisation.

Some Plutonium Working Group members remain opposed to these activities on various grounds including their concerns on safety, environmental and proliferation issues.

All consideration of management options by the Working Group have made the bounding assumption that irradiated MOX fuel produced as a product of a management strategy for existing stocks of separated plutonium would not be reprocessed. Any consensus or agreement reported must be considered to be qualified by this bounding assumption.

The Working Group wish to emphasise that this report seeks to explore the options available for the management of separated plutonium and identify the key issues and uncertainties associated with them. The report does <u>not</u> seek to advocate the merits of any option or to assume that any of the options will proceed, and should not be read as so doing.

Main Group:

The Main Group of the Dialogue accepts the above disclaimer and emphasises, in particular, that acceptance of the report should not be taken as an endorsement of: further plutonium separation; the production of MOX for use as fuel or for the immobilisation of plutonium; or the construction of new nuclear power stations.

Some members remain opposed to these activities on various grounds including their concerns on safety, environmental and proliferation issues.

The recommendations in the report must be read in the context of these disclaimers.

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Executive Summary

The Plutonium Working Group (PuWG) was set up following the Main Group meeting in November 1999, with a membership drawn from a wide range of stakeholders, including BNFL, trade unions, local government, the regulators, British Energy (BE) and the non-governmental organisation (NGO) community.

The overall objective of the PuWG was to develop and recommend principles for BNFL's management and reduction of separated plutonium stocks. The PuWG has achieved this objective through four main phases of work:

- reviewing current arrangements for the storage of separated plutonium, drivers for change and a preliminary screening of options for long term management;
- monitoring, reviewing and steering a BNFL study of long-term management options;
- examining key options using Strategic Action Planning (SAP); and
- analysing outputs, formulating recommendations, and drafting this final report.

In addition to identifying principles, the report makes a series of recommendations on the further explorations necessary to reach an informed decision on the future management of the plutonium stocks owned by BNFL. The PuWG wishes to stress that these recommendations are interconnected, and should not be selectively implemented. Nor should they be read as endorsing or advocating any specific option. Members of the PuWG hold diverse views on these options (see disclaimer).

The PuWG has undertaken its work against a backdrop of wide-ranging Government policy reviews, including on energy and radioactive waste management. The Government has also announced its intention to set up a Liabilities Management Authority (LMA)[11], which is likely to take legal and financial responsibility for the plutonium stocks currently owned by BNFL.

Although decisions on the adoption of specific long-term management options are therefore unlikely to lie with BNFL, the Company could in principle initiate explorations recommended by the PuWG. Against this background, the Main Group meeting in November 2002 endorsed this report and asked BNFL to formally consider and respond to its recommendations.

The report will also be of interest to the Department of Environment, Food and Rural Affairs (DEFRA) and the Department of Trade and Industry (DTI) because of its relevance to policy development on radioactive waste management and the future role of the LMA.

Drivers for Change and Preliminary Screening of Options

BNFL currently holds about 80 tonnes of separated plutonium, of which over 55 tonnes is owned by the Company. The plutonium is stored as plutonium dioxide powder in stainless steel cans, inside purpose-built stores, and is subject to international safeguards inspection.

Most of the PuWG consider that current arrangements are broadly acceptable in the medium term – that is, looking about 25 years ahead. However, most of the PuWG also consider that storage as plutonium dioxide powder is insufficiently 'passively safe' for the longer-term. In addition, increasing international pressure may well be applied in the future to reduce stocks of separated plutonium. An alternative management approach therefore needs to be developed in a timely manner, in the form of a clearly defined disposition programme. In the PuWG's view, 'timely' means that disposition should be underway within 25 years and complete within around 50 years.

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[11] During the final drafting of this report, the PuWG became aware that the Government would be re-naming the new body as the 'Nuclear Decommissioning Authority'.

Overall, the PuWG considers that a disposition programme should have two main objectives:

- plutonium should be converted to a ‘passively safe’ form, suitable for long-term storage or disposal, should the latter management route be chosen; and
- there should be a very high level of assurance that plutonium cannot be used illicitly outside the international safeguards regime.

After an initial assessment, the PuWG concluded that a range of options merited further examination, based on the following broad categories:

- immobilisation as a ceramic (including a ‘low spec’ mixed oxide (MOX) option), either with or without an additional radiation barrier;
- use as a nuclear fuel in existing or new build light water reactors.

We recognised that more information, particularly on business viability, and safety and environmental performance, was needed, and recommended that BNFL should initiate a study to generate this information and undertake further analysis.

The BNFL Study

The Company study took place between January 2001 and July 2002. The PuWG received and commented on interim reports as the study progressed. These comments were submitted to the Company Technical Executive (CTE), which then provided feedback. The PuWG would like to record its thanks to the individuals from the Company who have undertaken the study.

The study’s main findings, and the PuWG’s comments, are summarised below. This summary identifies significant areas of common ground between the PuWG and the Company, and the issues that remain outstanding.

Storage

- *Continued storage of separated plutonium cannot be viewed as a viable long-term solution (beyond around 25 years)*

The PuWG agrees with this conclusion.

- *Existing and planned plutonium stores at Sellafield do not preclude any management option from being pursued in the future*

Although this is true, there is concern in the PuWG that construction of new stores could lead to the extended storage of separated plutonium beyond the timescale that the PuWG and BNFL consider acceptable.

Immobilisation

- *Ceramic, rather than glass, waste forms are the preferred route.*

The PuWG agrees with this conclusion.

- *The addition of an external radiation barrier to immobilised plutonium is of doubtful value.*

The PuWG agrees with this conclusion because adequate security can be achieved in other ways (see below for the rationale).

- *Immobilisation of Pu as low spec MOX is not a preferred option, and will not be the subject of further work.*

Whilst recognising that there may be good reasons ultimately for rejecting this option, most of the PuWG consider BNFL's rejection of it to be inadequately justified. Further evaluation is needed to establish whether the option could be a viable contingency.

- *Immobilisation is the likely route for 5% of the stockpile, which is unsuitable for use as reactor fuel.*

The PuWG welcomes BNFL's recognition that some immobilisation will be required, but many of us can foresee scenarios where the proportion requiring immobilisation would be much higher.

- *The relative immaturity of plutonium immobilisation technology (lack of demonstration at the industrial scale) means that it cannot be viewed as an acceptable approach without a significant development programme.*

The PuWG accepts that substantial development is required, but sees no fundamental technical, safety or environmental reasons which would prevent a successful outcome. We would like to see a development programme more clearly set out.

Use as Reactor Fuel

- *Sizewell B could in principle use about a third of the current plutonium stockpile as MOX fuel. The advanced gas-cooled reactors (AGRs) present a number of practical difficulties but in principle could also use a significant amount. Magnox reactors do not present a viable option.*

The PuWG agrees with these conclusions, but notes the existence of significant hurdles to the use of MOX fuel in existing reactors.

- *Inert Matrix Fuels (IMF) offer encouraging potential, could be in commercial use within 10-15 year, and so will be pursued further.*

Although rejecting IMF on the grounds of technical immaturity during the first phase of its work, the PuWG recognises the advantages that it might offer over MOX fuel on grounds of intrinsic proliferation resistance and disposability.

- *The costs of generating electricity from new reactors will typically be in the range 2.2-3.0 p/kWh, which is comparable with other baseload sources. Use of MOX fuel rather than conventional fuels makes virtually no difference to the cost.*

The PuWG notes that no analysis of relative costs has been provided in the BNFL report to justify this assertion. It observes that cost estimates for new reactors depend critically on financial appraisal and plant parameter assumptions, and that other estimates of generation costs from new reactors have been higher, The PuWG accepts that MOX use is unlikely to make a significant difference to overall costs for new reactor construction and operation, but notes that the additional marginal costs (along with other factors), have so far deterred BE from using MOX in Sizewell B.

- *New build reactors of the AP600 or AP1000 type[12] present a viable option which could utilise 95% of the current stockpile. BNFL supports this option.*

The PuWG agrees that this option is technically viable, but notes that there are a number of substantial hurdles to a new build programme. It observes that the Company appears to be placing a lot of reliance on an option which may not come to fruition, and we consider that it should ensure that viable alternatives and contingencies are developed.

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[12] The AP600 and AP1000 are light water reactor designs from the Westinghouse company, judged to be typical in terms of features and capacity of designs which might be considered for any 'new build' programme.

Overall, there is some disappointment in the PuWG that the Company was not able to generate sufficient information – particularly on costs, business viability and risks – to enable a more detailed evaluation of options.

Security and Safeguards Issues

A Security and Safeguards Sub-group (SSSG) was set up by the PuWG in July 2000. One of the SSSG's main tasks was to give consideration to the worth of adding a radiation barrier to immobilised plutonium. The main conclusions, as endorsed by the full PuWG, were that:

- The vast majority of the UK plutonium stockpile is civil in origin and there are legal obligations for the material to remain subject to proper safeguards verification.
- The addition of a radiation barrier would complicate the existing safeguards methods for verifying plutonium oxide or fresh MOX and successful verification would require novel approaches that do not currently exist.
- The addition of a radiation barrier is of questionable benefit to the overall security of the plutonium. It may increase the difficulty of successful theft by increasing the intrinsic security of the stored plutonium but there are other ways of achieving adequate security that do not require the vast expense and technological challenge of an artificial radiation barrier. Nonetheless, there would be merit in examining further if other "intrinsic security" arrangements should apply.

The SSSG also considered the framework for civil nuclear security in the UK and the implications of the terrorist attacks in the US in September 2001. This was done, in part, through the exchange of written Questions and Answers with the Office of Civil Nuclear Security (OCNS). Although the SSSG regretted the low level of engagement by OCNS, it felt slightly better informed as a result of this exchange. However, a fundamental dilemma remains of how to provide real assurance about the adequacy of security arrangements without prejudicing security.

The PuWG concluded that there is a case for further consideration of security issues within the Dialogue, including where the boundary between confidentiality and transparency should lie, and on the security of the international transport of plutonium materials.

Strategic Action Planning (SAP)

The PuWG undertook strategic action planning to identify:

- the uncertainties associated with the implementation of different plutonium management options;
- the explorations that would have to be undertaken to reduce or resolve these uncertainties, or to enable the option to be implemented; and
- the contingencies which would be available if the uncertainties could not be resolved, or if implementation of a particular option proved not to be possible.

SAP is not a technique for comparing the pros and cons of different options, but provides a useful way of identifying the explorations needed to reach an informed decision on the future management of plutonium.

Simplified Options for SAP

Four options were examined:

- immobilisation as a ceramic in a purpose-built plant
- immobilisation as 'low spec' MOX in the existing Sellafield MOX Plant (SMP)
- manufacture of MOX fuel followed by use in existing UK reactors
- manufacture of MOX fuel followed by use in 'new build' UK reactors

Uncertainties

Three uncertainties common to all or most options were identified:

- *Waste form qualification*: none of the options could, realistically, be implemented until there is some assurance that the chosen waste form (low-spec MOX, purpose-designed ceramic or spent MOX fuel) is suitable for long-term storage or ultimate disposal. Currently, no system is in place to provide such assurance.
- *Stakeholder acceptability*: all of the options raise issues of concern for various stakeholders. For example, the extended storage of plutonium waste forms pending the adoption of another long-term management option (such as disposal) might not be acceptable to local communities.
- *Availability of the SMP*: the 'low spec' MOX and reactor options require the use of the SMP. Availability of capacity in SMP, and its timing, depends on whether BNFL's expectations for overseas MOX fuel contracts are realised.

A series of option-specific uncertainties were also identified. For example:

- *Immobilisation in a purpose-built plant*: principal uncertainties relate to optimum waste form, process specification and plant design, and, as a result, to costs and overall timetable.
- *Immobilisation as 'low spec' MOX*: principal uncertainties relate to waste form qualification and availability of the SMP.
- *Use of MOX in existing UK reactors*: principal uncertainties relate to waste form qualification, SMP plant capacity, commercial basis and public acceptability.
- *Use of MOX in new build UK reactors*: principal uncertainties relate to the Energy Review, regulatory and planning consents, commercial arrangements and public acceptability.

Recommendations on Explorations for Reaching Informed Decisions

These recommendations comprise our views on the explorations necessary to reach an informed decision on the future management of separated plutonium. They should not be read as advocating any of the individual options, or as assuming that any of the options will proceed.

As noted in the disclaimer, some members remain opposed to further plutonium separation, the production and use of MOX as fuel or for any other purpose, including immobilisation, or the construction of new nuclear power stations on various grounds including their concerns on safety, environmental and proliferation issues.

The recommendations that follow are all necessary to arrive at well-informed decisions about the long term management of separated plutonium. They should not be selectively implemented.

1. DEFRA should take the lead in establishing a waste form qualification system, which can be applied to potential plutonium waste forms, as a matter of urgency, taking into account the work currently being done for intermediate level wastes by the Health and Safety Executive (HSE), the Scottish Environmental Protection Agency (SEPA) and the Environment Agency (EA).

2. The 'plutonium owner'[13] should ensure that the development of detailed proposals for the management of separated plutonium, and the associated decision making, incorporate stakeholder engagement as an integral part of the process. Where appropriate, this should extend to the associated investigations.

[13] In future, this may be the LMA for plutonium that is currently owned by BNFL.

3. The ‘plutonium owner’ should disregard use of MOX in the Dungeness B, Hunterston B, Hinkley B, Hartlepool and Heysham 1 reactors as options for the management of separated Pu.

4. In the interests of fully establishing the practicability or otherwise of using MOX fuel in Sizewell B, Heysham 2 and Torness, and before any decisions on implementation are taken:

   - The ‘plutonium owner’ and BE (as the ‘plutonium user’) should enter into initial discussions to explore the financial basis for this option (NB This recommendation may change depending on outcome of current restructuring of BE).
   - The availability of capacity in SMP should be reviewed, taking account both of the duration and timing of fulfilling contract commitments to overseas customers and the feasibility of a life extension for the plant.
   - Should these explorations indicate that using plutonium in Sizewell B or either of the AGRs may be attractive from a liability management point of view, the ‘plutonium owner’ and ‘user’ should undertake a comprehensive environmental impact assessment including the evaluation of transport, reactor safety, environmental discharge, public safety (including the risks from extreme core disruption events), and waste form storage issues. This assessment should be conducted in consultation with stakeholders at national and local levels.

5. To explore the feasibility or otherwise of utilising plutonium, in the event that any programme of new build reactors were to proceed, we recommend that before any decisions are taken:

   - The financial basis on which plutonium might be utilised in new build reactors should be explored at an early stage between the ‘plutonium owner’ and the likely developer of any new build reactors. The existing collaborative agreement on new build between BNFL and BE may be a suitable vehicle for this.
   - The availability of capacity in SMP should be reviewed, taking account of the feasibility of a life extension for the plant.
   - Should these explorations (and the outcome of the energy review) be favourable to plutonium use in new build, the prospective developer should undertake a comprehensive environmental impact assessment on the proposal including the evaluation of transport, reactor safety (including the risks from extreme core disruption events), environmental discharge, and waste form storage issues. This assessment should be conducted in consultation with stakeholders at national and local levels.
   - A detailed comparison of MOX, IMF and conventional uranium fuels should be undertaken prior to deciding which fuel type to use.

6. In the light of long lead times, the ‘plutonium owner’ should commit promptly to an immobilisation research, process development and design study to more fully establish the optimum technology for plutonium immobilisation. This should include:

   - Underpinning research on ceramic immobilisation matrices
   - Consideration of possible plutonium loadings, inclusion of neutron absorbers, safety and safeguards requirements
   - Assessment of possible product forms against waste specification requirements
   - Design studies for process optimisation
   - Consideration of low spec MOX as an immobilised plutonium product

- A Best Practicable Environmental Option (BPEO) analysis, conducted with stakeholder involvement, which brings together findings of the above in order to establish the optimum process and waste form.

- A comprehensive environmental impact assessment on the proposal including the evaluation of plant safety, environmental discharge, and waste form storage issues. This assessment should be conducted in consultation with stakeholders at national and local levels.

The aim should be to make sure that immobilisation can be made available within a reasonable timeframe, and that the merits or otherwise of this approach can be taken properly into account before decisions about plutonium management are made.

7. In order to ensure the option of using SMP immobilised plutonium as low-spec MOX is not foreclosed, the 'plutonium owner' should, before final decisions about plutonium management are made:

   - Undertake a more detailed assessment of the suitability of low spec MOX as a form of immobilised plutonium product, including consideration of security, safety, safeguards, waste form qualification and other relevant issues.
   - Undertake a design study to establish whether SMP could feasibly be modified to produce a more 'optimised' plutonium waste form, either in current or newly added production lines.
   - Review the use of SMP in the light of the above investigations and those on the other options as recommended above, once the future contractual commitments of SMP for overseas and domestic customers become clearer.
   - Include the 'SMP option' in the BPEO for immobilisation options recommended in respect of new build plant.
   - Assess the findings of this investigation programme as part of the regular review of SMP operation alluded to in the White Paper 'Managing the Nuclear Legacy'.

8. Research and process development for plutonium immobilisation should concentrate on those options which do not involve an added external radiation barrier. However, other means of increasing the intrinsic security of the product should be explored.

9. At this stage, it is important to keep options open so that contingencies are available for each plutonium disposition option. In order to ensure this:

   - All the actions and explorations indicated above should be carried out to the point at which the 'plutonium owner' can make informed decisions (with stakeholder involvement) on the contribution each option should make to management of the plutonium stockpile.
   - In reaching these decisions, consideration should be given to: maintenance of contingency in the longer-term, community views on the long-term storage onsite of plutonium waste forms, socio-economic factors including employment, and the impact of plutonium stockpile management options on the wider Sellafield clean-up programme
   - The 'plutonium owner' should then develop a more detailed plan which shows how the options could be used to convert the current and projected future stockpile of separated plutonium into a passively safe form suitable for long-term storage and, potentially, ultimate disposal.
   - Such a plan should aim to achieve conversion to a timescale which would render construction of new plutonium dioxide stores, or refurbishment of existing stores unnecessary, except for compelling safety or security reasons.

Dissemination of this Report

In its recommendations to the November 2002 meeting of the Main Group of the National Stakeholder Dialogue, the PuWG:

- Commended the report to the Main Group as completion of the work of the PuWG;
- Recommended that the Main Group should ask the Company to formally consider and respond to the recommendations in the report, and invite the Business Futures Working Group to monitor the Company's response and make further recommendations as appropriate;
- Recommended that the Main Group should authorise publication of the report through The Environment Council as soon as practicable, subject to incorporation of any comments they have.

All of these recommendations were accepted, leading to the publication of this final version of the report.

The PuWG now commends this report to the wider audience of organisations and individuals with an interest in the management of plutonium stocks, both in the UK and elsewhere. The PuWG would like to encourage as wide as possible a dissemination of the information, analysis, findings and recommendations in this report and to express the hope that the report will make a useful contribution to informed decision making on this important issue.

1 Introduction

The Plutonium Working Group (PuWG) was set up by the Main Group of the BNFL National Stakeholder Dialogue and was convened following the Main Group meeting in November 1999.

The Main Group made a number of suggestions as to the aims of the Plutonium Working Group's work and the issues to be considered. Based on these suggestions, we initially set ourselves an overall objective in the light of the time and resources available:

'To develop and recommend principles for BNFL's management and reduction of separated plutonium stocks, having considered the available options and the issues identified by the November 1999 Main Group.'

The way in which the PuWG's work developed, based on this initial objective, is detailed in Section 2, below.

The PuWG has presented three interim reports to the Main Group, in November 2000, July 2001 and February 2002. All were subsequently published on The Environment Council website. This Final Report is presented as a self-contained document at the end of our programme of work: it therefore includes some material which has previously appeared in the interim reports, updated as appropriate.

The PuWG has met a total of 19 times between April 2000 and October 2002. A smaller Drafting Group has met on a number of occasions to consolidate descriptions of options and criteria, and to develop the PuWG's draft reports. These reports were then finalised and approved by the main PuWG.

Our discussions have taken place in an uncertain and changing environment, for example:

- The Government Energy Review and Managing Radioactive Waste Safely consultation are ongoing;
- The intention to form a Liabilities Management Authority, which is expected to take ownership of the Pu stockpile, has been announced;
- At the time of writing, the future of British Energy as a nuclear energy generation company was uncertain.

This report and the conclusions and recommendations which we make, should be read in that context.

Membership of the PuWG is summarised in Annex 1.

2 Evolution of the Work Programme

2.1 Introduction

The PuWG's work evolved in the four main phases set out in Table 1.

Table 1: Main Phases of Work

Phase	Time Period
Identification of drivers for change and preliminary option appraisal	Mar 00 - Nov 00
Monitoring, reviewing and steering a company study of plutonium management options; consideration of option appraisal methodologies and truncated Strategic Action Planning (SAP)	Dec 00 - April 02
Detailed Strategic Action Planning (SAP)	Apr 02 - Jul 02
Assessment of outputs and drafting of final report	Jul 02 - Oct 02

A description of the key features of these main phases is set out below. It explains: the nature of each phase; the reasons for evolution from one phase to the next; and which sections of the report cover the main outputs of each phase.

2.2 Identification of drivers for change and preliminary option appraisal

The first phase addressed the objective set by the Main Group (see Section 1). The first meeting of the PuWG took place in March 2000. The phase culminated with the PuWG's First Interim report, which was published in January 2001.

The First Interim Report:

- Reviewed the nature of UK plutonium stocks and storage arrangements;
- Identified drivers for change;
- Provided a broad definition of future management options;
- Undertook a coarse screening and refinement of the options;
- Developed criteria for assessment of the options;
- Made observations based on a preliminary qualitative assessment; and
- Made recommendations about developing a detailed analysis.

In terms of future work, the main recommendations were that: BNFL should produce proposals for a detailed analysis of plutonium management options, including the provision of information to enable analysis across all criteria; and that the PuWG should reconvene in December 2000 to review the Company's proposals and the future role of the Group.

A summary of the other main findings in the First Interim Report is provided in Section 3.

2.3 Monitoring, reviewing and steering a Company Study of plutonium management options

This phase started with agreement that: the Company should undertake a study between January 2001 and July 2002 to identify and assess those options which could assist in the management of its plutonium stocks; and the PuWG would provide an active monitoring, reviewing and steering role. The rationales for this approach were that: it would demonstrate the Company's commitment to address future plutonium management options; a detailed analysis would in any case have to rely heavily on the provision of information from the Company; and it would enable the PuWG's workload to be 'streamlined'.

An innovative feature of the agreed approach was that the PuWG would submit its comments to the Company Technical Executive (CTE) as the study progressed, and that the CTE would provide feedback on these comments. This was seen by the PuWG as a way of seeking to ensure the effectiveness of its reviewing and steering roles.

This phase of work has been described in the PuWG's Second and Third Interim Reports.

The Second Interim Report was produced for a Main Group meeting in July 2001 (and published in November 2001). It reviewed:

- The Company's preliminary appraisal of options for immobilising plutonium stocks (as of June 2001);
- The PuWG's comments on that preliminary appraisal;
- The CTE's response to the PuWG's comments; and
- A review of the PuWG's method of working.

Overall, the Second Interim Report concluded that the PuWG's work was being "effective in engaging BNFL with the issue of long term management of plutonium stocks". It also sought the agreement of the Main Group to the setting up of a Technical Sub-Group, which could enhance the monitoring and reviewing of the company study, thereby giving more time at full PuWG meetings for steering the study. This was endorsed by the Main Group.

The Third Interim Report was produced for a Main Group meeting in February 2002 (and published in July 2002[14]). It reviewed:

- The company's preliminary appraisal of options for using its plutonium as MOX fuel in nuclear reactors (dated September 2001);
- The outcome of a truncated version of Strategic Action Planning (SAP), undertaken by the PuWG to identify the most important areas of investigation for the remaining period of the company study (the 'SAP explorations list'); and
- The CTE's response (of January 2002) to the PuWG's SAP exploration list.

The CTE response made it clear that it would not be possible to undertake a number of the priority explorations within the remaining sixth months of the company study. It was decided, however, that one of the explorations - assessing the relative worth of adding an external radiation barrier to immobilised plutonium - would be undertaken in a PuWG Sub-Group, the Security and Safeguards Sub-Group.

Overall, the Third Interim Report concluded that the PuWG should focus on a more extended and intensive SAP analysis of plutonium management options, to run in parallel with the final months of the BNFL study. This approach was endorsed by the Main Group.

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[14] Publication of the Third Interim Report was delayed so that the PuWG could add some observations on the CTE response to the PuWG's SAP exploration list.

2.4 Detailed Strategic Action Planning

The purpose of undertaking a detailed SAP analysis is to identify: the uncertainties associated with implementation of different plutonium management options; the investigations which would resolve these uncertainties; and the contingencies which would be available if the uncertainties could not be resolved or if implementation of a particular option proved not to be possible.

The SAP analysis was undertaken at a series of PuWG meetings between April and July 2002. The main findings are presented and discussed in Section 5.

Two other main activities were undertaken during this phase:

- The Security and Safeguards Sub-Group (SSSG) considered the relative worth of adding an external radiation barrier to immobilised plutonium. A paper addressing this was endorsed by the full PuWG in April, along with a recommendation to the company. The paper and recommendation are summarised in Section 6, along with other outputs from the SSSG which have been endorsed by the PuWG.

- The PuWG initiated a programme of engagement with stakeholders with a clear interest in plutonium management, but who were not represented in the Group. These stakeholders were the Office of Civil Nuclear Security (OCNS), Nirex and the DTI[15]. The outcomes of this engagement are summarised in Section 7.

2.5 Assessment of outputs and drafting of final report

The final phase of the PuWG's work focussed on assessing the outputs of the previous two phases, and drafting the Group's final report.

The Company presented a draft version of the report of its study to a meeting of the PuWG in July 2002. Following comments, a revised report was prepared and presented at the September meeting of the Group. The PuWG's comments on the company report are set out in Section 4.

An overview of the key findings and recommendations from all phases of the PuWG's work is set out in Section 8.

[15] The DTI representative in the PuWG resigned in September 2001, due to a change of duties within DTI. No replacement was appointed.

3 Current Arrangements, Drivers for Change and Preliminary Option Appraisal

3.1 Introduction

This Chapter largely reports the findings from the first phase of the Group's work, referred to in Section 2.1 above, culminating in the publication of our First Interim Report. Our subsequent analysis (taking account of more recent developments) is in the Chapters that follow.

3.2 Current arrangements – and PuWG's initial agreements to scope the work

Some basic information about: the production and properties of plutonium; UK stocks and arisings of separated plutonium; and current arrangements for the storage of separated plutonium are given in Annex 2.

Having collated and discussed this information, PuWG agreed that:

- We would not make any distinction between the different forms and grades of plutonium in considering proliferation risks;
- We would focus our considerations on the management of existing and contractually committed future stocks of separated plutonium in the UK;
- We would use the figures for current and projected stocks of separated plutonium held at Sellafield as a basis for discussion, whilst recognising some participants' opposition to the further separation of plutonium (see disclaimer in the Foreword);
- We would accept that the ultimate fate of plutonium held by BNFL on behalf of other customers is not a matter which BNFL could decide unilaterally. Noting the importance of the quantities which are owned by BNFL, we agreed to focus our discussions on that portion of the plutonium stock which is BNFL-owned and hence BNFL's direct responsibility. In doing so, we note that any conclusions or recommendations reached will be relevant to other UK-owned stocks and to the wider international debate on the management and reduction of all separated plutonium stocks.

3.3 Drivers for change

For the purpose of discussion, we identified three time periods: the short term (the next 5 years); the medium term (the next 5 to 25 years); and the long term (beyond the next 25 years).

At the time when the first phase of the Group's work was carried out, most of the Group considered that the current storage arrangements are well developed and that the safety and security arrangements appear to be adequate for the short and medium term - that is, for about the next 25 years. This conclusion is of course conditional on the maintenance of robust security and safeguards arrangements and also on the maintenance to a high standard of the storage facilities, the repackaging facilities, and all the associated operational procedures. Others questioned these arrangements on a number of grounds[16] - see also Chapters 4 and 6. Most of the Group also considered that there are two main drivers which create pressure for change in the medium term. Firstly, the storage of plutonium dioxide powder cannot be considered 'passively safe' in the context that is likely to be considered appropriate for the long term storage of radioactive materials.[17] Thus, most of the Group considered that current arrangements are not appropriate for

[16] Briefly, the grounds raised by some members were that: concerns that stores are not completely inaccessible to terrorists; the extent to which plutonium powder is or can be truly contained in the stores; the stability of the plutonium powder and the acceptability of producing it when there are no known 'disposal' routes; whether 'safeguards' could really detect or deter diversion of plutonium to a nuclear weapons programme; and the potential for accidents causing plutonium contamination of workers and/or the public.

[17] The 1995 radioactive waste management White Paper describes the principle of 'passive safety' as seeking to ensure that a material "..is immobilised and the need for maintenance, monitoring or other human intervention is minimised", Cm 2919, July 1995, para 52. Some members of the group questioned the use of

indefinite storage and that regulatory pressure for change will be likely. Secondly, one might expect increasing international pressure to reduce stockpiles of separated reactor grade plutonium which, in the absence of a clearly foreseen end use, could dictate the need for change from the current storage of plutonium as separated $Pu0_2$ to an alternative. Some members of the Group also emphasised that, in their view, there should be an end to reprocessing, in order that no additional quantities of separated plutonium would be added to the stockpile.

It is apparent to us, as it was to the Royal Society[18] in 1998, that there is no clear strategy for the management of these plutonium stocks in the longer term. BNFL informed us that these stocks are currently regarded by the Company as an asset with zero value. During the course of the Group's work, a Government consultation on nuclear waste management policy posed, amongst other issues, the question of whether some or all of UK stocks of separated plutonium should be reclassified as a radioactive waste. The Government's announcement of 29 July 2002 on the outcome of that consultation indicated[19] that relevant waste management assessments would now proceed for at least some of the UK stocks.

We urge DEFRA and DTI to have regard to this report of the PuWG, for the purpose of their planning and carrying out such assessments.

Any major reclassification would of course create a substantial financial liability on BNFL and other UK owners of plutonium, to cover long term management including the possibility of ultimate disposal. It would also raise issues for current UK strategies for the management of radioactive waste and spent fuel, since plutonium is not currently classified as a waste.

Most of the Group consider that storage of plutonium as plutonium dioxide powder in its present form does not meet the standards of 'passive safety' which are likely to be required for long term storage. Therefore, an alternative approach to the management of plutonium stocks needs to be developed.

We feel it is important that any change to the current storage arrangements for existing plutonium stocks should be carefully considered and should be substantiated by a comprehensive analysis covering the short, medium and long terms (using our nominal classification of these timescales as above). This view, which underlies our work in steering the Company Study (Section 4) and our Strategic Action Planning (Section 5), implies that the analysis will need to take account of the significant investigation and development, in addition to the design and construction of new facilities, that may be required.

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the term 'passive safety' since they did not agree that plutonium stocks could ever be regarded as passively safe. These members nevertheless agreed that plutonium waste forms should be as stable as possible for long-term storage.

[18] Royal Society, 'Management of Separated Plutonium', February 1998.

[19] The announcement included the following statement: "The waste from our existing nuclear facilities will arise over the next century or so. So we intend, in our assessment of waste management options, to include not only materials currently classified as waste but also to consider the consequences of providing for other materials which may be have to be managed as waste during that period, such as some separated plutonium, and uranium, as well as certain quantities of spent nuclear fuel. The future management options for the UK's civil plutonium include its possible use as a fuel. However, up to 5% of this stock may be so contaminated that, even though it may also be technically possible to treat and use this amount for fuel, it might prove uneconomic to do so. The Government is currently undertaking a study of the possible options for the future management of UK owned civil stock and will want to consider the results of that exercise before reaching its own conclusions on this issue. More generally, the Government urges the other owners of these materials, on a voluntary basis, to put in hand procedures now which would allow them to identify those materials which may become not economically reusable." DEFRA News Release, 315/02, 29 July 2002.

3.4 Preliminary option appraisal for the long term management of separated plutonium

3.4.1 Objectives for the management of separated plutonium

Our initial discussions on options for the longer term management of separated plutonium quickly identified a large number of specific processes or technologies which were potentially relevant. However, we recognised that we needed to find some way of defining options which could be subject to more detailed evaluation and which could also be used to set some boundaries between our considerations and those which have been looked at by other Working Groups.

For the purpose of our current deliberations, we concluded that the end point of any viable option for the management of separated plutonium should be the conversion of plutonium into a 'passively safe' form, suitable for long term storage. Most of the group also consider that the converted plutonium should be in a form readily amenable to disposal because this is a management strategy which may ultimately be implemented. However, some members question the ultimate viability of disposal[20].

Because of the reliance placed by the US and Russia on the 'spent fuel standard', we had considerable discussion on whether compliance with this standard should be an absolute requirement for the management of UK separated plutonium stocks. The spent fuel standard requires, in essence, that plutonium stocks should be as "unattractive and inaccessible for retrieval and weapons use as the residual plutonium in spent fuel"[21]. If a 'radiation barrier' equivalent to the radiation levels from spent nuclear fuel would need to be incorporated in the 'package' of stored plutonium, this would of course restrict the range of acceptable options for plutonium management.

As explained in Section 6, below, through the Security and Safeguards Subgroup's considerations we eventually reached a consensus that the achievement of the 'spent fuel standard' was of questionable benefit for assuring the security of BNFL's separated plutonium stocks in the future. We further agreed that any management strategy for BNFL's separated plutonium stocks must provide a very high level of assurance that plutonium cannot be extracted illicitly for use outside the current international non-proliferation safeguards. This might be achieved through a combination of physical and institutional security arrangements, together with the physical and chemical form of the conditioned plutonium (to make extraction difficult).

3.4.2 Broad definition, preliminary screening and refinement of options

During the first phase of our work, we determined that the options for management of separated plutonium, as alternatives to the existing practice of continued storage, could be grouped into a number of broad classes or concepts – definitions of which are given in Annex 2 - as follows:

- Transmutation
- Immobilisation, with or without a radiological barrier
- Use of plutonium in Mixed Oxide fuels
- Use of plutonium in Inert Matrix fuels
- Other uses of plutonium, e.g. in mixed plutonium/thorium fuels

[20] Some members of the PuWG consider that there is no such thing as final 'disposal' of radioactive wastes because any 'disposal' site would eventually leak and contaminate the environment. They also expressed concern at the possibility of criticality incidents should control over plutonium wastes be abandoned and they prefer a permanently-managed store, with the built-in opportunity for retrieval in future.

[21] US Department of Energy, 'Record of Decision for the Surplus Plutonium Disposition Final Environmental Impact Statement', January 2000.

We went through a process of defining in a little more detail what each of the options might entail, and screening the options against the 'headline' criteria of technical feasibility; business viability; workforce and socioeconomic factors; proliferation resistance; safety and environmental factors; and public and political acceptability. Initially we were looking for 'show stoppers' which would exclude options from more detailed consideration. The process was iterative, and after some refinement and a lot of discussion we reached the following conclusions:

We consider that plutonium management options involving transmutation, or novel fuel cycles such as thorium/plutonium fuels, should not be considered as means of dealing with BNFL's current stockpiles of separated plutonium. This is because the technology required is far too immature and the options cannot be implemented within the timescale which we consider appropriate (that is, around 25 years).[22]

Although recognising the opposition of some members of the group to the use of plutonium as a reactor fuel (see disclaimer in Foreword), we agreed that there should be further assessment of the following broad options:

- Immobilisation;
- Immobilisation with an added radiological barrier; and
- Use as Mixed Oxide or Inert Matrix fuel.

We proceeded to develop a more detailed description of a range of options, which could form the basis for further, more detailed assessment. In doing so, we rejected a number of possibilities on the grounds of feasibility and/or existing information about their likely effectiveness.

We also clarified our position on continued storage of $Pu0_2$ powder. The main variants of continued storage can be described as:

- Interim storage (as plutonium dioxide powder): using present arrangements until an alternative is implemented[23]; and
- Long term or indefinite storage; with re-packaging and replacement of stores as necessary.

We had already rejected long term or indefinite storage of plutonium as plutonium dioxide powder as an option (section 3.2). However we retained interim storage as an option in our assessment - although none of us regarded it as a complete 'solution' - because it will be a component of any management strategy, and also because it constitutes a useful 'benchmark' against which other options can be considered.

A large number of immobilisation options can be identified. These depend upon:

- Material form: whether the plutonium is immobilised in ceramic or glass (and in what type of ceramic or glass);
- Radiological barrier: whether a radiological barrier is added and, if so, of what type, and whether this is intimately mixed with ('homogeneous'), or arranged externally to ('can in canister'), the ceramic or glass; and
- Use of existing facilities or new build: whether the option can be implemented using existing facilities or requires new plant.

[22] Some members subsequently expressed further concerns about the quantities of radioactive waste generated by such options and other potential environmental impacts (eg discharges). Others pointed out that the costs of a transmutation-based plutonium disposition programme are likely to be high.
[23] The working group did not associate the term 'interim storage' with a specific timescale.

We noted that 'homogeneous' vitrification of plutonium along with highly active fission products had been rejected in the US on the grounds that that this option was much less attractive than the can-in-canister options, based primarily on lower technical feasibility, much higher costs, and longer timescales for implementation[24]. Similarly, the glass can-in-canister option has been rejected in the US on the grounds that it is inferior to the ceramic can-in-canister alternatives, based on the assessment that the glass form is less robust to extraction of plutonium; expected to be less durable in the repository environment; and likely to involve significantly higher costs[25]. In addition, the proportion of plutonium which could be incorporated into such a waste form might be a limiting factor. **We therefore excluded the homogeneous vitrification and glass can-in-canister options from further consideration. We did, however, initially retain two vitrification options: the first entails the immobilisation of plutonium by vitrification using the existing vitrification plant at Sellafield, without inclusion of an additional radiation barrier[26]; and the second entails the immobilisation of plutonium in a ceramic form with the addition of an external vitrified high level waste barrier (i.e. ceramic can-in-canister).**

BNFL advised us that the existing vitrification lines were fully committed (as a requirement of the HSE) to reduce highly active liquor stocks to buffer levels by 2015, that subsequent modifications would be extremely difficult because of the highly radioactive nature of the existing process, and that the difficulty would be exacerbated because the plant as it stands does not require any features to prevent criticality accidents.

As a result of this information we concluded that use of the existing vitrification plant for the vitrification of Pu should be discounted as a feasible option.

Although recognising the opposition of some members of the group to the use of plutonium as a reactor fuel (see disclaimer), a large number of Mixed Oxide fuel options can be identified for further assessment. These options may be classified according to the type of reactor, whether a reactor is currently operating or requires construction, and whether the reactor is sited in the UK or overseas.

Of the possible reactor types, we considered the use of Mixed Oxide fuel in Magnox reactors, fast reactors, or heavy water reactors, should be rejected as options for further consideration. Although at first we also rejected Advanced Gas Cooled Reactors, these were subsequently included in our SAP analysis[27] (see Section 5).

The rationale for this is as follows. BNFL informed us that it has rejected the use of Mixed Oxide fuel in Magnox reactors on the grounds of very tight time constraints and external risks, including regulatory considerations and the likelihood of political opposition. In the short term, there is no likelihood of new gas-cooled reactor construction in the UK. The development of fast reactors has been abandoned in the UK and there are major question marks over technical and economic viability in the short and medium term. We rejected heavy water cooled reactors on the grounds that any new UK build is likely to involve “advanced” light water cooled reactors and not heavy water reactors.

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[24] US Department of Energy, ‘Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives’, DOE/NN-0007, January 1997, p108-126.

[25] Lawrence Livermore Laboratory, ‘Design Only Conceptual Report: Plutonium Immobilisation’, Bechtel, UCRL-131617 Rev 1, January 1999, p13-14.

[26] This option was retained because the use of existing plant offers a potentially low-cost route to plutonium immobilisation.

[27] Initial information from British Energy indicated that the use of Mixed Oxide fuels in Advanced Gas Cooled Reactors (AGRs) would raise serious difficulties with regard to practicability, worker dose, safety case, and economics. From our subsequent considerations, it seemed that the difficulties might not be insurmountable within the projected lifetime of some AGRs, and further evaluation of this option would be worthwhile.

From the above considerations we arrived at a list of 17 detailed options, in total, for the long-term management of separated plutonium. These are explained in our First Interim Report. The number of options in broad classes was as follows:

- Immobilisation: 4
- Immobilisation with a radiological barrier: 4
- Use as nuclear fuel in existing light water reactors: 4
- Use as nuclear fuel in new build reactors: 5

3.4.3 *Qualitative assessment of options*

We considered versions of our list of options on several occasions in the first phase of our work, and during this iterative process we developed a set of criteria which we found helpful in evaluating the options. Our initial list of criteria was very long, but we found they could be grouped into a number of 'headline criteria' which we felt formed a good basis for assessment, given the level of detail about each option which we were able to consider. Our final listing of headline criteria was:

- Technical feasibility
- Business viability
- Socio-economics
- Safety and environment
- Proliferation resistance
- Public and political acceptability

By using these headlines, together with the more detailed criteria which underlay them, we reached the following views:

1 The direct vitrification of plutonium in the existing vitrification plant at Sellafield ranked poorly on most of the criteria. **We considered this option should be excluded from further consideration.**

2 Of the remaining options spanning immobilisation, immobilisation with a radiological barrier, and use as fuel it is not possible to judge whether there is a single option or group of options which emerges as a clear 'winner' by ranking consistently high against all criteria. This was in part because we did not have sufficient information to devise ratings against some of the headline criteria, nor sufficient time to seek to reach consensus in the Group for those headline criteria where ratings were produced by subgroups. In addition, judgement as to the best options would depend on how much importance is attached to each of the criteria - in other words, how one might 'weight' considerations of proliferation resistance against safety and environment against business viability, and so on.

3 More detailed information - particularly on business viability – would have helped develop our analysis, but it was doubtful that the choice of a preferred option or options would become clear cut and it was likely that further differences of opinion within the Group would arise due to differing opinions of the weights to ascribe to each criterion in making a choice.

Some members of the group were frustrated by our inability to make more progress by this means. However, our qualitative assessment did help to identify the major issues for consideration and led to progress during the subsequent stages of our work that are discussed in the following Chapters.

4 Commentary on the Company Study

4.1 Introduction

As a result of its first phase of work, the PuWG recommended that BNFL should produce proposals for a detailed analysis of plutonium management options. The Company agreed and outlined a programme of work, the objective of which was ".. the identification and assessment of those options which would assist in the management of BNFL's plutonium stocks."

The PuWG's second phase of work then became to monitor, review and steer the Company Study. This entailed receiving and reviewing progress reports, and submitting comments to the Company Technical Executive (CTE), which then provided feedback to the PuWG. As explained in Section 2.3, this process included three main reporting stages:

- The Company's preliminary appraisal of immobilisation options (June 2001);
- The Company's preliminary appraisal of options for using MOX fuel in nuclear reactors (September 2001); and
- First draft of the Company study (July 2002).

A second draft of the Study was presented to the PuWG in September 2002. The PuWG was informed that this version of the Study had been approved by the CTE.

The PuWG would like to record its thanks to the individuals from the Company who have undertaken the Study.

The purpose of this Section is to provide a commentary on the September 2002 draft of the Company Study, which is attached as Appendix 3. The commentary is structured as follows:

4.2 Overview
4.3 Storage of Separated Plutonium
4.4 Immobilisation Options
4.5 Reactor Options
4.6 Evaluation of the Process

In Sections 4.3 – 4.5, the commentary identifies areas of common ground between the PuWG and the Company, and comments on issues that remain outstanding. Section 4.6 provides an evaluation of the process used in the second phase of the PuWG's programme.

4.2 Overview

The PuWG's original expectations of what the Company Study would deliver were based on:

- The recommendation in the First Interim Report that the Company provide sufficient information to enable clearer choices to be made between plutonium management options. The recommendation highlighted the need for information on business viability and safety and environmental performance.

- The Company's original study proposal, which included: screening of options against technical feasibility, safety and hazard potential, and business viability; assessment and identification of process flow sheets, plant requirements, throughput rates, lifetimes and costs and finally, an evaluation and ranking of options[28].

[28] 'Proposal to Co-ordinating Group for PuWG Work in 2001/2', Appendix 3, Second Interim Report, November 2001.

Against this background, most of the PuWG is disappointed that the Company Study fails to provide the anticipated level of information provision and analysis. This is particularly the case in relation to costs and business viability, safety and hazard potential and the systematic evaluation and comparison of management options. There is also concern that insufficient information and analysis has been provided to support some of the Study's conclusions (see further explanation below). This concern is compounded where such conclusions coincide with the Company's pre-existing policy.

Nonetheless, there are still some important areas of common ground between the PuWG and the Study, as outlined below.

4.3 Storage of Separated Plutonium

The Company study makes three key points about the storage of separated plutonium:

- continued storage is an acceptably safe, secure and safeguarded option for the near future;
- storage cannot be viewed as a viable long-term solution (beyond around 25 years); and
- existing and planned plutonium stores at Sellafield do not preclude any management option from being pursued in the future.

Common Ground

The second key point provides a highly significant area of common ground. In essence, this is that **current storage arrangements can only be viewed as an interim measure and other management options should be underway within a 25 year timeframe.** This shared conclusion takes into account the drivers for change outlined in Section 3.3.

Outstanding Issues

On the first key point, at the end of the first phase of work, most of the PuWG concluded that current storage arrangements are well developed and appear to have adequate safety and security features. The concerns of those who did not share this view were subsequently exacerbated by the events of September 11, 2001, as referred to in Section 6 below.

Although welcoming the assurance provided in the third key point, **there is concern that the Company's plans to construct a new plutonium store at Sellafield could lead to the storage of separated plutonium beyond an acceptable timeframe** (see Section 5). It is noted that the study describes the new store as "long term", which appears to contradict the shared conclusion highlighted above. The study adds that the store is designed to be able to accept both THORP and Magnox designed packages, so will be able to accommodate historical or future plutonium as required.

Recommendation

In the light of these concerns, ***we recommend that:***

- **The Company provide the Main Group with further information about the rationale and timetable for constructing the new store and an explanation of how the rationale can be reconciled with the conclusion that storage of separated plutonium cannot be viewed as a viable long-term solution; and**
- **The Main Group refer this issue to the Business Futures Working Group so that it can monitor developments and comment accordingly.**

4.4 Immobilisation Options

Common Ground

Following a literature review, technical assessment, trial BPEO exercise and risk review, the Company study concludes that ceramic waste forms are preferred over vitrified glass. It adds that: “unless a major breakthrough is made internationally, BNFL does not plan to sanction development work on the direct incorporation of plutonium dioxide into glass as a method of immobilisation.” **The PuWG welcomes this finding, which supports and strengthens the conclusion it reached in its First Interim Report.**

The Company study also reports on a 5 year collaborative research programme with the University of Cambridge, which is examining the use of synthetic mineral analogues as host phases for actinides and plutonium. The programme includes three main activities: understanding the fundamentals of radiation damage in ceramics; examining the durability of potential ceramic waste forms; and examination of active samples. **The PuWG welcomes this programme, which provides an opportunity to carry forward important research in this area** (see further comment below).

The study also expresses scepticism about the value of adding an external radiation barrier to immobilised plutonium waste forms and highlights the practical difficulties that this would pose for existing verification regimes. **This is a further area of common ground with the PuWG** (see Section 6 for further details).

Outstanding Issues

The primary outstanding issue is on the low spec MOX option. The position outlined in the Company Study can be summarised as follows:

- The low spec MOX option has not been assessed as part of the technical assessment, trial BPEO or risk review and the Company does not intend to pursue it further;
- ‘Dual operation’ (producing low spec MOX and MOX fuel through adjacent manufacturing lines) is impractical;
- MOX fuel manufacture will continue to the end of the operating life of the SMP, after which the plant would require considerable refurbishment, thereby negating the potential economic benefit claimed for low spec MOX;
- Low spec MOX would not achieve ‘intrinsic security’ qualities that exceed (a) plutonium dioxide powder or (b) MOX fuel; and
- It may be preferable to examine immobilised forms that provide a higher degree of ‘intrinsic security’.

Most of the PuWG is disappointed that the Company has not examined the low spec MOX option in its study and considers that the option has been dismissed too lightly[29]. There is concern that the option has been rejected on policy grounds, rather than as a result of a systematic appraisal of immobilisation options.

Most of the PuWG consider that there is a need to keep options open, particularly in the light of the uncertainty about the duration of the operation of the SMP as a fuel manufacturing plant. These members also take the view that further evaluation is needed to establish whether the low spec MOX option can be viewed as a viable contingency (see the SAP analysis in Section 5). A contribution to this evaluation might be made by including low spec MOX within the collaborative research programme with Cambridge University.

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[29] As stated in its Second Interim Report, the PuWG recommended to the CTE in June 2002 that the low spec MOX option be included in the Company Study. The CTE response stated that it had agreed to ask for some work to be carried out on ‘what if’ scenarios of the type suggested by the PuWG. This work appears not to have been carried out.

In addition, most of the PuWG consider that the stated reason for rejection of the low spec MOX option lacks logic and requires more careful appraisal. For example, low spec MOX does offer 'intrinsic security' qualities that exceed plutonium dioxide powder and could be subject to further improvements (such as storage in containers which are difficult to move without specialist equipment). Although there may ultimately be good reasons for rejecting the low spec MOX option, these have not been identified in the Company Study.

With regard to immobilisation in general, other outstanding issues are:

- The Company Study concludes that immobilisation is a likely candidate for a part of the UK stockpile (around 5%) for which technically feasible, but costly, pre-treatment prior to MOX fuel manufacture would be required. **Although welcoming the acknowledgement that immobilisation is a likely candidate for part of the stockpile, it is noted that the Study does not provide sufficient information and analysis to justify the conclusion that this should apply to only around 5% of the stockpile.** It is possible to foresee circumstances (see Section 5) where immobilisation could be a candidate for a larger fraction of the stockpile; some PuWG members can foresee circumstances where all of the stockpile would be immobilised

- The Company Study concludes that technical and economic uncertainties associated with the relative immaturity of immobilisation options mean that immobilisation cannot yet be viewed as an acceptable long-term solution without a significant development programme. **We recognise the uncertainties and need for further development, but see no technical, safety or environmental reasons that could be expected to prevent a successful outcome.**

- The Company Study makes reference to the requirements of a development programme for immobilisation, but does not state whether, and if so how, such a programme will be carried forward. **The PuWG considers that clarification of how the Company intends to move forward is needed.**

- The study contains very little information on the costs of different immobilisation options. Most of the PuWG is disappointed that further progress has not been made. It is noted **that the original intention to assess options against business viability has not been achieved.**

- **The Company Study refers to the US decision not to proceed with plutonium immobilisation using the can-in-canister approach, but does not refer to the reasons for this decision.** These relate to the higher costs which would have resulted from pursuing a twin track approach (immobilisation and MOX fuel use)[30], rather than any technical, cost, safety or environmental problems with immobilisation.

[30] In March 2001, the twin-track approach was estimated to cost $6.3 billion. This was broken down into four main components: a Pit Disassembly and Conversion Facility, $2.2 billion; MOX fuel fabrication and use, $2.5 billion (assuming 33 tonnes of Pu); immobilisation, $1.5 billion (assuming 13 tonnes of Pu); and various support systems, $0.15 billion. See US DOE, 'Report to Congress on the Projected Life Cycle Costs of the US and Russian Fissile Materials Disposition Programs', 30 March 2001.

Recommendations

In the light of these concerns, **we recommend that the Company:**

- **Formulate a development programme for immobilisation which takes into account the findings of the PuWG's SAP analysis (see Section 5);**
- **Include in this development programme an evaluation of whether low spec MOX can be viewed as a viable contingency; and**
- **Consider whether part of this evaluation can be undertaken by including low spec MOX within the collaborative research programme with Cambridge University; and**
- **Inform the Stakeholder Dialogue of its response to these recommendations and how it intends to move forward.**

4.5 Reactor Options

Common Ground

There are two main areas of common ground. The first concerns the potential use of MOX fuel in existing UK reactors. The Company Study concludes that Magnox reactors do not present a viable option, the AGRs present a number of practical difficulties and Sizewell B could in principle use about a third of the current plutonium stockpile over its lifetime. **These findings support the conclusion that the PuWG reached in its First Interim Report.**

The second concerns the Study's conclusion that inert matrix fuel (IMF) offers encouraging potential and so will be pursued further. Although rejecting IMF on grounds of technical immaturity during the first phase of its work, the PuWG recognises the advantages that it might offer over MOX fuel on grounds of intrinsic proliferation resistance and disposability. It also notes the Company view that commercial use is possible within a 10-15 year period. **If a programme of new reactor build, involving Pu disposition, is started in the UK we consider that a detailed comparison of MOX and IMF should be undertaken prior to deciding which fuel type to use.**

Outstanding Issues

These are as follows:

- The Company Study concludes that of future reactor systems, the AP600 or AP1000 both represent viable options and expresses support for MOX fuel use in a new build programme. Although the new reactors may be viable from a technical point of view, the PuWG notes that there is a range of hurdles to a new build programme, including policy, business viability and public acceptability issues. **The PuWG observes that the Company is placing a lot of emphasis on a plutonium management route that may not come to fruition. The Company should ensure that viable alternatives and contingencies are developed** (see Section 5).

- The Company Study asserts that the costs of generating electricity from new reactors will typically be in the range 2.2 – 3.0 p/kWh, and that the lower cost could be achieved by a series of twin reactors, thereby making nuclear generation comparable to other sources for baseload electricity. **The PuWG observes that cost estimates depend critically on financial appraisal and plant parameter assumptions but that the study does not provide any explanation or justification for the Company's assumptions.** It is noted that after reviewing such assumptions, the Cabinet Office Performance and Innovation Unit concluded that an overall range of generating costs of 3 – 4 p/kWh is more realistic[31].

[31] PIU, 'The Economics of Nuclear Power', Energy Review Working Paper, February 2002.

- The Company Study asserts that the utilisation of MOX fuel in a reactor, compared with the use of conventional uranium oxide fuel, makes virtually no difference to the overall generating cost of the electricity produced. **The PuWG notes that no analysis of relative costs is provided to justify this assertion.** It also observes that although the Company's claim is likely to be true when estimating the overall costs of electricity for new reactors[32], the additional financial and political costs associated with the required modification to Sizewell B, along with the cost differential between MOX and conventional uranium fuel, currently deters British Energy from using MOX fuel in Sizewell B.

- The Company Study includes "safety and hazard potential" as a key criterion for evaluating all options and refers to MOX licensing implications. **The PuWG considers that risk assessments regarding the use of MOX or IMF must include high consequence events for both accidents and terrorist attacks.** For example, Lyman[33] indicates the higher consequences of extreme events for MOX-fuelled reactors compared with uranium fuels.

Recommendations

In the light of the commentary above, **we recommend that:**

- **If a programme of new reactor build, involving Pu disposition, is started in the UK, a detailed comparison of MOX and IMF should be undertaken prior to reaching decisions about which fuel type to use.**

- **The Company should not focus exclusively on a plutonium management route, which assumes the construction of new nuclear reactors in the UK, but should ensure that viable alternatives and contingencies are developed (see Section 5).**

- **Risk assessments regarding the use of MOX fuel or IMF should include high consequence events for both accidents and terrorist attacks.**

4.6 Evaluation of the Process

The PuWG considers it important to evaluate the process of monitoring, reviewing and steering a Company study, so that lessons can be learnt.

It therefore makes the following observations:

- *Information Provision*: as explained above, most of the PuWG is disappointed that the Company Study did not provide the anticipated level of information provision, particularly on the costs of different options. Difficulties with information provision on costs appear to be a re-occurring problem within the dialogue[34]. This suggests that the Coordination Group should give some consideration to potential solutions to this problem.

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[32] This is because estimates for the overall costs of electricity from new reactors are dominated by capital costs and, to a lesser extent, operation and maintenance costs.

[33] Lyman E, 'The Impact of the Use of MOX Fuel on the Potential for Severe Nuclear Plant Accidents in Japan', Nuclear Control Institute, October 1999.

[34] The lack of information provision on costs was a contentious issue within the Spent Fuel Management Options Working Group.

- *Inherent Limitations in the Steering Role*: although welcoming the opportunity to provide comments to the CTE and receive feedback, most of the PuWG is disappointed that its steering role has had a lack of impact on the scope and content of the Company Study. A primary reason appears to lie in the inherent limitations of an advisory role, particularly where PuWG advice is contrary to Company policy.

- *Comparison to the Socio-Economic Study Model*: in this case a stakeholder steering group was formed to oversee a study which was undertaken by independent contractors. This model gives stakeholders more control over the scope and content of a study, compared with the PuWG's limited role in the Company Study on plutonium management options.

- *Option Appraisal Methodologies*: the original expectation that the company study would culminate in a detailed evaluation and ranking of options did not come to fruition for a variety of reasons. The PuWG observes that even if such an assessment had been attempted, it is unlikely that it would have identified a single preferred option agreed by all members of the PuWG[35]. It also considers that there would have been advantage in undertaking a SAP analysis either before, or at a very early stage of the Company Study, so that its scope and priorities could have been based on the findings of a SAP analysis.

Recommendations

In the light of these observations, **we recommend that:**

- **the Coordination Group discuss possible solutions to the problem of lack of information provision about costs and report back to a future Main Group meeting;**
- **working groups be encouraged to give careful consideration to the pros and cons of different models for undertaking detailed studies before deciding which one to adopt;**
- **working groups be encouraged to adopt realistic expectations about the potential for, and value of, detailed Multi-Attribute Decision Analyses; and**
- **if wishing to embark on a detailed study of contrasting approaches to the management of a particular category of radioactive materials, working groups be encouraged to consider whether a SAP analysis should be undertaken first, so that the scope and priorities of the study are informed by SAP findings.**

[35] The Spent Fuel Management Options Working Group found that its detailed Multi-Attribute Decision Analysis confirmed a divergence of views on the weighting to be applied to five key criteria.

5. Strategic Action Planning

5.1 Introduction

As explained in Section 2, towards the end of our second phase of work we had decided that the Strategic Action Planning approach offered a useful way for us to explore the issues and uncertainties associated with the different options for plutonium management. This decision was influenced in part by the experience of the Spent Fuel Management Options Working Group, who had also found the technique useful, and in part by our experience of using a truncated version of the technique to identify uncertainties which needed to be addressed in BNFL's ongoing study.

5.2 Nature of Strategic Action Planning

'Strategic action planning' (SAP) is an approach within the 'management of uncertainty' portfolio. Our application of SAP involved the systematic analysis of possible future courses of action, under the headings:

- Assumptions
- Issues and uncertainties
- Actions
- Explorations
- Deferred actions (or decisions)
- Contingencies

Strategic Action Planning is **not** a technique for comparing the merits and demerits of different options[36]. In a SAP analysis of a single option, it is necessary to enter into a frame of thinking whereby the option **will** proceed, and within that frame of thinking to identify characteristics of the option which have to be true, or actions which have to be taken, for this to be the case.

Within our group members held diverse and conflicting views on the options - some favouring one type of option over another, others having fundamental objections on points of principle to one or more of the options. Once we were able to enter into the right frame of thinking, SAP provided a very useful framework for exploring the implications of the different options and identifying important areas of uncertainty which, if resolved, **may** reduce the diversity and conflict of views.

Assumptions are used in strategic action planning where uncertainty exists and cannot be easily or quickly reduced. These are made explicit and then clearly stated. The key question is: *What assumptions are being made in order that this option can or will proceed?*

Uncertainties and issues emerge quite naturally from identification of the assumption - if we have found it necessary to assume something, there must be an uncertainty or unresolved issue which has forced us to make that assumption. The key question is: *What didn't we know that obliged us to assume this?*

Actions are what is to be done in the short term. These should be largely independent of any uncertainty, that is things which will need to be done regardless of the resolution of uncertainty. The key question is: W*hat short term actions are required in order for this scenario to be pursued?*

Explorations are investigations aimed at reducing the uncertainty relevant to an assumption and often are intended to support decisions which can safely be put off to a future date (or deferred - see below). The key question is: *What needs to be known in order that the uncertainty can be reduced? How can we find out?*

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[36] SAP can provide some limited comparative judgements, for example, relative degrees of uncertainty between options.

Deferred decisions or actions are decisions, or actions, which can be safely deferred – often pending the outcome of the reduction of uncertainty by explorations. Such decisions are usually deferred because they present a risk if they are taken now (based on an assumption) which outweighs any risk associated with 'no action'. Deferring a decision, in effect, demands that explorations be undertaken in order to reduce uncertainty and inform the decision when it is taken. The key questions are: *Which decisions or actions can be deferred? When do the decisions have to be made or implemented? What explorations are necessary to inform the decision, and can they be made in time?*

Contingencies are the courses of action which are available in the event that the assumption turns out to be wrong. When a number of options are being considered it is common for one scenario to be the ultimate contingency for another. The key question is: *what can be done if explorations show that our assumption is wrong?*

The aim of the strategic action planning is to make underlying assumptions explicit, to identify the explorations which are necessary to test those assumptions and develop contingency plans for situations where assumptions turn out to be wrong. The plan necessarily focuses in detail on the short term, because the outcome of explorations cannot be predicted. The nature of the plan also tends to discourage the foreclosure of options because of the need to identify contingencies.

In the case of plutonium management, the options we have identified all to some extent provide contingencies for each other (albeit with some conflict which we discuss below). However implementation of any of the options depends on many assumptions with attendant uncertainties, so that our SAP work has necessarily concentrated on identifying the explorations which need to take place in order to properly establish the viability or otherwise of each of the options, and has inevitably led us to the conclusion that none of the main options which we have identified should be foreclosed at this stage.

None of the discussion which follows should be taken as detracting from the preferences for, or fundamental objections against, particular options held by different members of the group. However we believe the explorations and actions identified, taken in their entirety, are the most appropriate way of objectively testing our preferences and objections and enabling decision makers to move forward in an informed way.

5.3 Setting up the SAP Analysis

During Phase 1 of our work, we had identified seventeen distinct options for the management of separated plutonium. Conducting a SAP analysis is quite time consuming and to fully analyse seventeen separate options would have been impracticable for us. Analysing all seventeen options would have been of limited value as the actions and explorations for many of them would have been similar; moreover, the parallel discussions taking place in the Security and Safeguards sub-group were indicating that some options (principally those with an added radiation barrier) may present no advantage over options which were subject to considerably less uncertainty. To proceed, we selected four options which we felt would cover the range of issues and uncertainties which it was most important to resolve:

Option	Description
R2	Conversion of PuO_2 into MOX followed by use in existing UK reactors
R3	Conversion of PuO_2 into MOX followed by use in 'new build' UK reactors
I1	Conversion of PuO_2 into immobilised ceramic form in purpose built immobilisation plant
I2	Conversion of PuO_2 into 'low spec' MOX, unsuitable for reactor use, in existing Sellafield MOX plant (SMP)

There were two important ‘boundary conditions’ to these options:

- The end point of all the options, as considered in our analysis, was Pu converted into an immobile and passively safe form suitable for very long term storage pending decisions on final disposal. We did not consider uncertainties associated with final disposal itself, except for the issue of waste qualification (see below), which is needed so that the UK would still be able to pursue the option of final disposal in the future, if it eventually chose to do so.
- The reactor options are defined for the purpose of our analysis as ‘once through’, that is the irradiated or spent MOX is regarded as the immobilised Pu product and is not reprocessed. Any agreement or consensus regarding reactor options which is implied by the text of this report is conditional on that definition.

We identified assumptions and uncertainties and the associated actions and explorations under a number of specific headings:

Reactor options	Immobilisation options
Interim PuO_2 storage	Interim PuO_2 storage
Fuel manufacture Reactor operations	Product manufacture
Waste management	Waste management
Transport	Transport
Policy	Policy
Regulation	Regulation
Societal issues	Societal issues
Costs and funding	Costs and funding

In this way, we ensured that we covered the full course of each of the options in a comparable manner. The approach also helped to identify uncertainties which were common to one or more of the options.

In addition to identifying uncertainties, actions, explorations and contingencies under each of these headings we worked up a ‘timeline’ for each of the options which we could use to establish urgency of, or deadlines for, particular actions and explorations. The timelines also enabled us to identify conflicts between options, when adoption of one option might effectively foreclose on or more of the others, and to identify times at which contingencies might be required and the likelihood of their availability.

This process enabled us to draw out key findings by focussing on the actions and explorations required in the short to medium term, the time constraints dictating the availability of particular options and the contingencies which would be needed if the option proved not to be viable.

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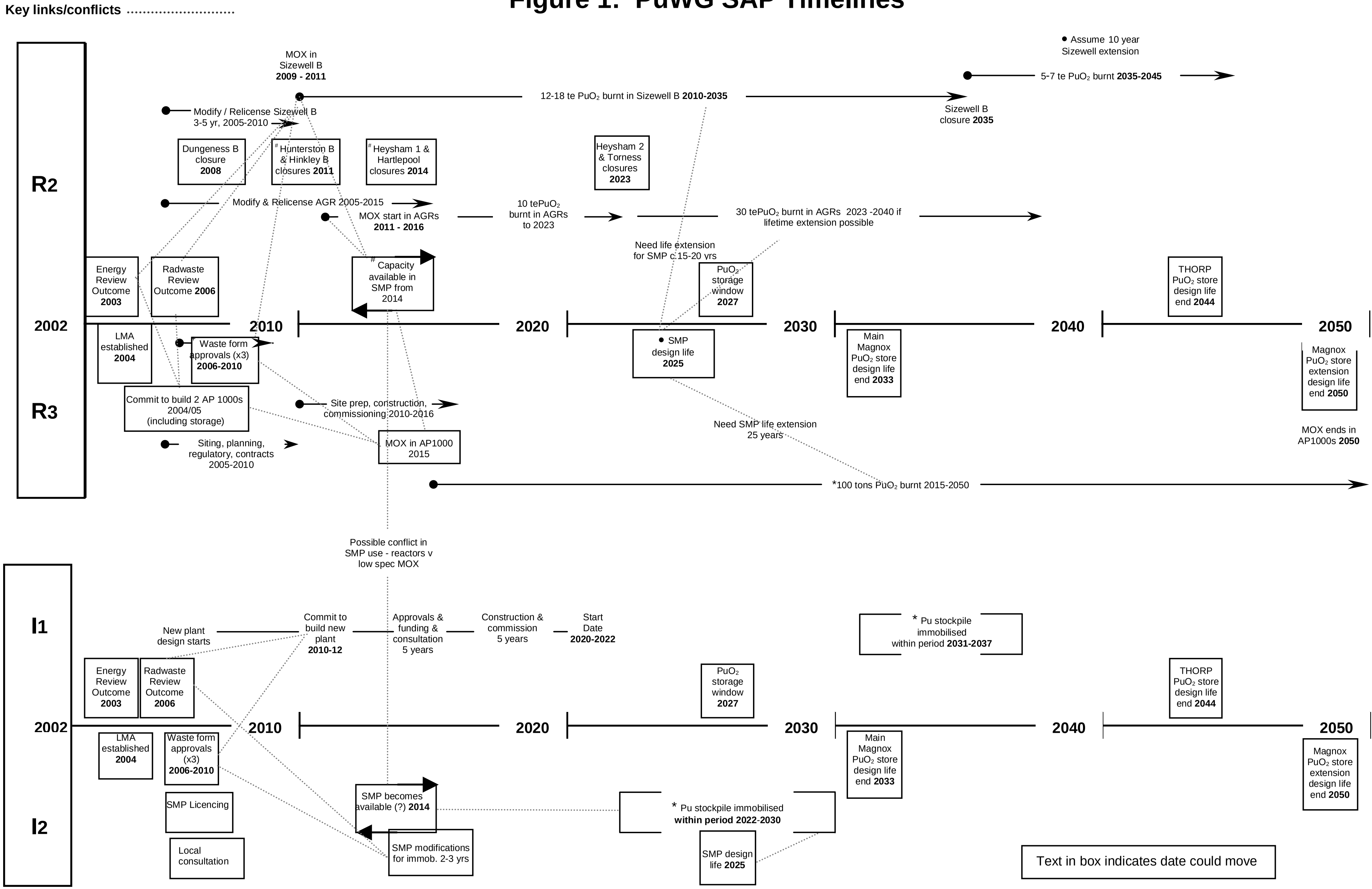
NB Text in box indicates date could move

Figure 1: PuWG SAP Timelines



5.4 Timelines

The timelines which we developed are shown in Figure 1. Although we developed these when we had completed much of the SAP analysis on assumptions, uncertainties, actions, explorations and contingencies they are very helpful in bringing out key conclusions and recommendations from the SAP analysis. We hope that presenting a summary before discussing the outcome of the SAP analysis itself will prove helpful to the reader. Dates in the timelines are not intended to be precise and are based on the collective judgement of the group rather than any definite or settled timetable.

The key features of each of the timelines can be summarised as follows.

<u>Policy and industry structure</u>

- The outcome of the Energy review, expected in 2003, is likely to influence the reactor based options, particularly the option involving new build reactors.
- No clear decision or commitment on Pu stockpile management can be expected before the LMA is established (expected to be in 2004/5).
- The outcome of the Radwaste review, expected in 2006, may influence all of the options.
- None of the options is likely to proceed beyond study or design stage until there is some assurance that the wasteform chosen is likely to be acceptable for some form of ultimate disposal (see below). Such assurance is not likely to be available before 2010.

<u>Pu oxide storage</u>

- The main Magnox Pu oxide store building has a design life which extends to the end of 2033. Extension of this life until the end of 2050 may be required to support some of the options.
- The THORP Pu oxide store has a design life which extends to the end of 2044. Extension of this life beyond 2050 may be required to support some of the options.

<u>R2 - MOX in existing UK reactors</u>

- It may take 3 to 5 years to modify and relicense Sizewell B to accept MOX.
- Taking account of the need to resolve contractual issues, it is unlikely that MOX could be loaded into Sizewell B before 2010.
- Sizewell B has a design life extending to 2035. Between 2010 and 2035 we estimate Sizewell B could convert 12 to 18 tonnes of Pu as MOX.
- If the life of Sizewell B could be extended to 2045, this would allow another 5 to 7 tonnes of Pu to be converted, making 17 to 25 tonnes in all.
- It would take about 10 years to modify and relicense AGR reactors to accept MOX.
- It is unlikely that MOX could be loaded into any AGR reactor before 2015.
- The design lives of Dungeness B, Hunterston B, Hinkley B, Hartlepool and Heysham 1 expire before 2015. It does not seem feasible for these reactors to convert any Pu.
- Heysham 2 and Torness currently have design lives extending to 2023. In the period between 2015 and 2023 we estimate that these reactors could utilise about 10 tonnes of Pu; assuming life extensions to 2040 would increase the Pu convert to 40 tonnes in total[37].

[37] The Royal Society, 'Management of Separated Plutonium' (1998), has estimated that a single AGR could use plutonium at a rate of between 0.4 and 1.2 tonnes per year, but that it may take 10 years to build up to this utilisation rate. Based on life extension of Heysham 2 and Torness to 2040, we have assumed 10 years at an average of 0.5 tonnes per year per reactor and 15 years at 1 tonne per year per reactor, starting in 2015.

- BNFL currently anticipates contractual demand for manufacture of overseas MOX until 2014, and the plant has a design life extending to 2025. In order to maximise use of Sizewell B availability of some capacity earlier than 2014 would need to be established; to fully support either Sizewell or AGR options a substantial life extension would be required.
- Use of SMP for this option would preclude its use for immobilisation of Pu as low spec MOX.

R3 - MOX in new build UK reactors

- 2004/2005 is the earliest date at which a commitment to build new reactors could be expected.
- Taking account of contractual issues, planning and regulatory issues, construction and commissioning, a new reactor could not be available to accept MOX before 2015.
- If we assume two AP1000 units were constructed and operated with a high MOX loading, 100 tonnes of plutonium could be converted between 2015 and 2050. Additional AP1000 units would increase the total *pro rata.*
- A substantial extension of SMP design life would be necessary to support this option.
- Use of SMP for this option would preclude its use for immobilisation of Pu as low spec MOX.

I1 - Immobilisation in a new build immobilisation plant

- Taking account of research, design, regulatory, construction and commissioning phases a new build immobilisation plant is unlikely to be operational before 2020.
- Processing capacity would depend on the design but it appears feasible to immobilise the entire Pu stockpile during the period 2020-2037.
- This option can operate alongside any combination of the other options.

I2 - Immobilisation as low spec MOX in SMP

- If BNFL's expectations for overseas MOX contracts are realised, this option would not be able to proceed until SMP has completed those obligations, which at present are anticipated to extend to about 2014.
- A further 2-3 years would be required for plant modifications, making SMP available for low spec MOX production by about 2017.
- Using this route the Pu stockpile could be immobilised as low spec MOX by about 2030.
- Use of SMP for this option would preclude its use for production of MOX for consumption in existing or new build UK reactors.

5.5 Near-term Uncertainties, Actions and Explorations

As a result of our work, and noting both the current state of progress in BNFL's studies and international progress generally, it is apparent that much of the information which would allow decisions to be made about the optimum option or combination of options for management of the separated Pu stockpile simply does not exist.

In that situation, we consider that none of the options should be foreclosed. Although our SAP analysis has considered aspects of the whole plutonium disposition programme for each of the options, we only feel able to reach conclusions and recommendations concerning actions and explorations in the near term (the next 5 to 10 years), which are aimed at progressing the necessary investigations and decision making so that the plutonium stockpile can be rendered passively safe in a timely manner.

We discussed the drivers for change in Section 3, where we concluded that the present arrangements for the storage of separated plutonium as oxide powder were broadly acceptable in the medium term - that is, looking about 25 years ahead. 'Timely', in our view, would mean that plutonium disposition was underway within 25 years and it would be reasonable to expect that disposition would be complete within 50 years.

Therefore, in order to provide some boundary on 'timeliness', we consider that a 'timely' programme would not require the construction of any new stores for plutonium oxide, nor any refurbishment or life extension of stores, much beyond 2050, except for compelling safety or security reasons.

The full output of our SAP analysis is attached as Annex 4. From this analysis, the principal near term uncertainties, actions and explorations for each option are summarised below.

5.5.1 Uncertainties common to all options

The SAP analysis highlights waste form qualification as critical for all of the options. If plutonium currently stored as oxide powder is to be converted into a form which is passively safe and suitable for long term storage and/or disposal, some degree of assurance that the chosen wasteform does not foreclose long term management options, including disposal, is essential. In the absence of such assurance, there is a substantial disincentive to proceed with the implementation of any option. At present there is a policy 'vacuum' in this area and there is no way in which the owner of the plutonium can establish waste form qualification.

We have concerns that the need for a wider waste form qualification system appears not to have been recognised in the MRWS process to date, and feel that:

- ***A waste form qualification system which can be applied to immobilised forms of plutonium should be developed relatively promptly as part of the development of policy for the interim management of wastes (i.e. not be bound up in the longer staged MRWS process on policy for long term management);***

- ***The work should include consideration of extending the Letter of Comfort system to a wider range of wastes.***

We recommend DEFRA should take the lead in establishing a waste form qualification system as a matter of urgency, taking into account the work currently being done for intermediate level wastes by HSE, SEPA and EA.

All four options which we have considered for use of Pu in reactors or immobilisation involve the long term storage of plutonium in a passively safe form as a prelude to its possible ultimate disposal. This raises a number of planning and public acceptance issues, even for sites where material is currently stored. The socio-economic impacts of the various options raise further issues which need to be taken into account by decision makers. Public acceptance across transport and a range of other potential areas of concern is also a major issue for each of the options.

We welcome the general commitment to stakeholder engagement in the White Paper 'Managing the Nuclear Legacy' and we anticipate that the LMA, once formed, will take on ownership of the BNFL 'stockpile' of separated plutonium and will wish to reach its own views on the best way forward for management of plutonium stocks.

We recommend that the development of detailed proposals for the management of separated plutonium, and the associated decision making, should incorporate stakeholder engagement as an integral part of the process. Where appropriate, this should extend to the associated investigations.

We commend this report to the LMA as an initial contribution to this process.

The availability of processing capacity in the SMP is an important uncertainty in three of the four options. Uncertainty about early availability of capacity arises from whether BNFL's expectation for contracts to produce MOX for overseas customers will be realised[38]. This is relevant to MOX manufacture for existing UK reactors and to the production of low spec MOX as an immobilised plutonium product. Uncertainty also affects late availability of capacity. This is influenced by the success of plant operation and the feasibility of extending plant life, and is relevant to MOX manufacture in an extended programme of Pu utilisation in new build reactors.

5.5.2 Reactor options - existing reactors

It is technically feasible to use the Sizewell B reactor to utilise some plutonium as MOX fuel, producing irradiated MOX fuel as a waste form[39]. As noted in the discussion of timelines, about 18 tonnes of plutonium could be utilised within the currently stated reactor lifetime. Given a reasonably foreseeable extension of reactor lifetime this total could be increased to about 25 tonnes.

Using Pu in AGR reactors is more problematic, as significant modifications to the fuel loading systems would be required in order to control operator doses. The remaining lifetimes of Dungeness B, Hunterston B, Hinkley B, Hartlepool and Heysham 1 are short and these reactors do not appear to present sufficient capacity for the use of plutonium to justify the necessary modifications. However, Heysham 2 and Torness could use about 10 tonnes of plutonium within their current planned lifetime and a further 30 tonnes if life extension to 2040 were possible.

Thus, whilst existing reactors could not use all of the plutonium stocks, they could potentially make a significant contribution to the reduction of stocks.

The principal uncertainties regarding the use of plutonium in existing reactors appear to be waste form qualification (as discussed above), commercial considerations, SMP plant capacity, and public acceptance.

BE have indicated in the past that they see no commercial case for the use of MOX fuel in Sizewell B (or AGRs). This judgement is, however, based solely on the commercial assessment of MOX as a reactor fuel, on the assumption that MOX (rather than conventional uranium fuel) is purchased at the current commercial rate. The proposition to use reactors as a means of managing the plutonium stockpile is quite different. There is clearly a motive for the 'plutonium owner' to offer the 'plutonium user' incentives to accept MOX, if this would avoid the need for the 'plutonium owner' to incur costs on other options for the management of plutonium stocks. Therefore, the overall cost to the 'Pu owner' and the financial attractiveness to the 'Pu user' can only be established through a negotiation between the parties involved. This negotiation would also have to take account of the costs of other options for the management of Pu.

Availability of fuel manufacturing capacity in SMP is an important uncertainty determining the amount of Pu which can be used in existing reactors. If the contracts with overseas customers currently anticipated by BNFL do indeed fully utilise plant capacity until 2014, no MOX for use in UK reactors could be manufactured in SMP before then; extension of SMP life beyond the current nominal date of 2025 would be necessary to fully utilise the potential for Pu burning in Sizewell B and/or AGRs.

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[38] The PuWG is aware that a substantial proportion of these contracts is anticipated by the Company to be with Japanese utilities. Significant uncertainties arise from recent developments in Japan, 'TEPCO's Plutonium programme on Ice', NuclearFuel, 2 September 2002, p1 and 11, and 'Impact of Affair on Deregulation, Fuel Cycle Policy will be profound', Nucleonics Week, 5 September 2002, p10.
[39] As a bounding assumption for our assessment, we have assumed irradiated MOX will not be reprocessed (see section 5.3).

Public acceptance of transport of MOX to the reactor, utilisation of MOX in the reactor, and of subsequent management of the spent MOX is also a key uncertainty.

We recommend that the 'Pu owner' should disregard use of MOX in the Dungeness B, Hunterston B, Hinkley B, Hartlepool and Heysham 1 reactors as useful options for the management of separated Pu.

Sizewell B, Heysham 2 and Torness should be regarded as potential options but recognising that the latter two reactors (AGRs) are more problematic in terms of the requirement for significant plant modifications.

We recommend that, in the interests of fully establishing the practicability or otherwise of this option and before any decisions on implementation are taken:

- ***The Pu owner and BE (as the 'Pu user') should enter into initial discussions to explore the financial basis for these options (NB: This recommendation may change depending on outcome of current restructuring of BE).***

- ***The availability of capacity in SMP should be reviewed, taking account both of the duration and timing of fulfilling contract commitments to overseas customers and the feasibility of a life extension for the plant.***

- ***Should these explorations indicate that using Pu in Sizewell B, or either of the AGRs, may be attractive from a liability management point of view for both parties, we recommend that the Pu owner and the Pu user should undertake a comprehensive environmental impact assessment (EIA)[40] on the proposal including the evaluation of transport, reactor safety, environmental discharge, public safety and wasteform storage issues. This assessment should be conducted in consultation with stakeholders at national and local levels.***

5.5.3 Reactor options - new build

It is clearly feasible, in principle, to build sufficient new reactors to consume the Pu stockpile within a reasonable time. Our figures suggest that two AP1000 reactors, together with the capacity available in Sizewell B, could convert the Pu stockpile entirely by about 2035. However, whether this option would prove to be feasible in practice depends on a number of complex factors.

First, new build would need to achieve at least 'no objection in principle' at policy level in the outcome of the current Energy Review. The degree to which any positive encouragement or discouragement of new build is manifest in review recommendations would be very important factors.

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[40] An EIA is a wide ranging assessment of the impact of a major new development which includes consideration of issues such as effects on the local infrastructure (including transport) and economy, effects on land use and wildlife habitats, effects of discharges on the environment and health, risks associated with major accidents and many other issues. One important feature of the EIA is that it requires consideration of means of ameliorating any adverse effects and incorporates amelioration at the planning stage, rather than during or after development. EIAs are required under an EU Directive for major developments including the construction of new nuclear reactors. An EIA would probably not be required under statute for the introduction of MOX into an existing reactor. Nonetheless we recommend the EIA as a suitable framework for systematically examining and evaluating the issues involved. Similarly, EIAs require a form of consultation during the process, usually in presenting results or conclusions about chosen options. We are recommending a higher degree of stakeholder involvement in the more formative stages of the assessment.

Secondly, the commercial arrangements on which any new reactors are built and operated, whether or not any Pu is burnt within them, are likely to be complex and present uncertainty. New reactors may be built with the prime purpose of burning Pu or with the prime purpose of burning conventional uranium fuel and the subsidiary purpose of burning Pu. The terms on which Pu may be burnt would be determined by negotiations between the two parties involved, and possibly investors who were providing the capital financing for the project. These negotiations would probably be most complex if Pu burning were a substantial part of the justification for new build.

Thirdly, proposals for new reactor build would, under current procedures, involve a major planning application and, almost certainly, a public inquiry. Amongst all the other issues which would need to be covered, we anticipate that the basis on which the site (or sites) for the proposed construction are selected would be a key issue. In drafting the timeline of Figure 1 we have assumed contractual, regulatory and planning issues could be resolved in the period 2005-2010 with construction then commencing. To meet this timetable streamlining of current planning procedures would need to be in place. Some recent proposals in this area[41] have been dropped, so our assumption that construction could begin in 2010 may be optimistic.

Finally, the uncertainties associated with waste form qualification and public acceptance for transport[42], reactor operations and storage/disposal of irradiated MOX would apply to new build just as for the Sizewell B option.

The earliest start date for Pu burning in new reactors would be consistent with SMP first completing its currently anticipated contractual obligations to overseas customers; but, as for Sizewell B, a substantial life extension of SMP would be required to support the Pu burning programme through its lifetime, raising uncertainty as to whether the programme could be fully supported by MOX manufacturing capacity.

In order to establish the feasibility or otherwise of this option we recommend that, before any decisions are taken:

- ***The financial basis on which Pu might be utilised in new build reactors should be explored at an early stage between the Pu owner and the likely developer for any new build reactors. The existing collaborative agreement on new build between BNFL and BE may be a suitable vehicle for this.***

- ***The availability of capacity in SMP should be reviewed, taking account of the feasibility of a life extension for the plant.***

- ***Should these explorations (and the outcome of the energy review) be favourable to Pu use in new build, we recommend that the prospective developer should undertake a comprehensive environmental impact assessment (EIA) on the proposal including the evaluation of transport, reactor safety, environmental discharge, and wasteform storage issues. This assessment should be conducted in consultation with stakeholders at national and local levels.***

[41] DTLR, ‘Major Infrastructure Projects: Delivering a Fundamental Change’, December 2001.
[42] Transport issues would be minimised if the new build were to be at the Sellafield site.

5.5.4 Immobilisation options: new build immobilisation plant

In contrast to the reactor options, immobilisation of BNFL's Pu stockpile in a new build immobilisation plant could be a relatively straightforward proposition in a financing and contractual sense if the Pu owner is prepared to bear the full cost. In that case, the Pu owner would be the only party involved in making the key investment decisions. This option also effectively de-couples management of the plutonium stockpile from operations in SMP.

However, the necessary technology has not been established at an industrial scale and the principal uncertainties are associated with optimum product, process specification and plant design, with consequences for uncertainty in the cost and overall timescale of the project.

As for reactor options, waste form qualification is a key uncertainty. Public acceptance issues in relation to long term storage/disposal of the immobilised product are also equally applicable. However transport would not be a significant uncertainty if (as seems most likely) the immobilisation plant were constructed at Sellafield.

In the light of long lead times, we recommend that the Pu owner commits promptly to an immobilisation research, process development and design study to more fully establish the optimum technology for plutonium immobilisation. This should include:

- ***Underpinning research on ceramic immobilisation matrices***
- ***Consideration of possible Pu loadings, inclusion of neutron absorbers, safety and safeguards requirements***
- ***Assessment of possible product forms against waste specification requirements***
- ***Design studies for process optimisation***
- ***A BPEO analysis, conducted with stakeholder involvement, which brings together findings of the above in order to establish the optimum process and waste form***
- ***A comprehensive environmental impact assessment (EIA) on the proposal including the evaluation of plant safety, environmental discharge, and wasteform storage issues. This assessment should be conducted in consultation with stakeholders at national and local levels.***

The aim should be to make sure that this option can be made available within the period suggested by our timeline in Figure 1, and that the merits or otherwise of this option can be taken properly into account before decisions about plutonium management are made.

5.5.5 Immobilisation options: low spec MOX in SMP

The use of SMP to immobilise the Pu stockpile by manufacture of 'low specification MOX', that is MOX which is not suitable for use in reactors, has some attractions as a potentially low cost route to immobilise plutonium using established technology and a plant which is already constructed.

The option faces the uncertainties of wasteform qualification and long term management/disposal of the immobilised product which are common to all the other options. Transport issues would not present significant uncertainty because operations (other than the possibility of final disposal in the long term) would be confined to the Sellafield site.

However our timeline indicates that the principal uncertainties in timing for this option relate to the assumptions that manufacture of low spec MOX could not proceed whilst SMP were also being used to produce reactor grade MOX for overseas customers, and also that BNFL's expectations for overseas MOX contracts are borne out. These assumptions critically affect the attractiveness or otherwise of this option and need to be kept under review.

Although costs for the low spec MOX route may be lower than for the purpose built plant in the short term, the purpose built plant would permit the production of a wasteform optimised for volume, long term integrity and resistance to future re-separation of Pu. It is possible that long term management costs may negate the short term cost advantage of the low spec MOX route.

Use of the low spec MOX route following completion of current SMP contracts would also (on present assumptions) preclude the use of SMP for manufacturing MOX for use in in either existing or new build reactors in the UK.

Nonetheless, the low spec MOX route may become attractive once there is availability of SMP for this purpose.

We note that the report of BNFL's studies does not consider low spec MOX to be a favourable option (see Section 4.4). We agree that this may be the case in some future scenarios (e.g. timely availability of the new build immobilisation option or a significant UK commitment to a new build reactor programme). However, recognising the significant uncertainties facing all of these options, we believe it inadvisable to foreclose any options at this stage.

Therefore, in order to ensure this option is not foreclosed we recommend that the Pu owner should, before final decisions about plutonium management are made:

- ***Undertake a more detailed assessment of the suitability of low spec MOX as a form of immobilised Pu product, including consideration of security, safety, safeguards, waste qualification and other relevant issues.***

- ***Undertake a design study to establish whether SMP could feasibly be modified to produce a more 'optimised' Pu wasteform, either in current or newly added production lines.***

- ***Review the use of SMP in the light of the above investigations and those of the other options as recommended above, once the future contractual commitments of SMP for overseas and domestic customers become more clear.***

- ***Include the 'SMP option' in the BPEO for immobilisation options recommended in respect of new build plant.***

- ***Assess the findings of this investigation programme as part of the regular review of SMP operation alluded to in the White Paper 'Managing the Nuclear Legacy'.***

5.6 Conclusions and Recommendations

At this stage, we consider that it is important to keep options open so that contingencies are available for each of the options. In order to ensure this we recommend that:

- ***All the actions and explorations indicated above should be carried out to the point at which the Pu owner can make informed decisions (with stakeholder involvement) on the contribution each option should make to management of the plutonium stockpile.***

- ***These considerations should include maintenance of contingency in the longer term, community views on the long term storage onsite of Pu waste forms, socio-economic factors including employment, and the impact of Pu stockpile management options on the wider Sellafield clean-up programme.***

- ***The Pu owner should then develop a more detailed plan which shows how the options could be used to convert the current and projected future stockpile of separated Pu into a passively safe form suitable for very long term storage and, potentially, ultimate disposal.***

- ***Such a plan should aim to achieve conversion to a timescale which would render construction of new Pu oxide stores or refurbishment of existing stores beyond that currently foreseen, unnecessary.***

We also recommend that:

- ***DEFRA should take the lead in promptly establishing a waste form qualification system which can be applied to immobilised forms of plutonium, taking into account the work currently being done for intermediate level wastes by HSE, SEPA and EA (see Section 5.5.1).***

6 Security and Safeguards Issues

6.1 Introduction

A Security and Safeguards Sub-Group (SSSC) was set up by the PuWG in July 2000. The initial purpose was to examine security and safeguards issues relating to the management of the UK plutonium stockpile and the disposition options under consideration by the full PuWG. Following the events of September 11, 2001, the Coordination Group asked the SSSG to take into account a wider range of security issues.

The SSSG's work has consisted of three main streams:

- Specific studies to examine: (a) the security and safeguards requirements of the main plutonium management options under consideration by the PuWG; (b) the security and safeguards relevance of adding a radiation barrier to immobilised plutonium; and (c) the relative ease with which plutonium can be extracted from MOX.

- Discussion of the regulatory framework for civil nuclear security in the UK and the implications of the terrorist attacks in the US in September 2001.

- Engaging the Office for Civil Nuclear Security in discussion about civil nuclear security in the UK.

The first two streams are considered in Sections 6.2 and 6.3 below. The third stream is considered in Section 7, 'Engagement with Wider Stakeholders'.

Membership of the SSSG was drawn from specialist and interested members of the PuWG and consisted of Dave Andrews, Fred Barker, Frank Barnaby, Roger Howsley, Paul Leventhal and David Lowry.

6.2 Specific Studies Relevant to Plutonium Management Options

6.2.1 Security and Safeguards Requirements of Plutonium Management Options

This topic was addressed by the SSSG in the period July-September 2000. The conclusions are set out in Part A of the SSSG working paper attached as Annex 5. **The main conclusions drawn in September 2000 were:**

- **Existing storage arrangements are robust[43] and, given the UK's status as a Nuclear Weapons' State, the plutonium was not currently considered to be a domestic proliferation threat.**
- **The security and safeguards "challenges" and requirements for producing and managing spent MOX fuel and immobilised plutonium with an added radiation barrier are comparable and can be achieved.**

At the time of this work, there was a difference of opinion within the SSSG on the worth of adding a radiation barrier to immobilised plutonium.

[43] Following the events of September 11, 2001, this conclusion has been revisited through Q&A exchanges with the OCNS. See Section 7.

6.2.2 Adding a Radiation Barrier to Immobilised Plutonium

As explained in Section 2.3, the SSSG was subsequently asked to give further consideration to the worth of adding a radiation barrier to immobilised plutonium, following discussion between the PuWG and the CTE in early 2002.

The outcome of this further assessment is set out in Part A of the paper attached as Annex 5. **The main conclusions are as follows:**

- **There is no internationally agreed definition for the spent fuel standard and it only has relevance in the context of international, bilateral nuclear weapons disarmament initiatives.**
- **Nuclear materials recovered from military programmes are not necessarily safeguarded and verified to the same standards as civil nuclear materials.**
- **The vast majority of the UK plutonium stockpile is civil in origin and there are legal obligations for the material to remain subject to proper safeguards verification[44].**
- **The addition of a radiation barrier would complicate the existing safeguards methods for verifying plutonium oxide or fresh MOX and successful verification would require novel approaches that do not currently exist.**
- **The addition of a radiation barrier is of questionable benefit to the overall security of the plutonium. It may increase the difficulty of successful theft by increasing the intrinsic security of the stored plutonium but there are other ways of achieving adequate security[45] that do not require the vast expense and technological challenge of an artificial radiation barrier. Nonetheless, given the PuWG's view that an alternative approach to the management of plutonium stocks needs to be developed, there would be merit in examining further if other "intrinsic security" arrangements should apply.**

The working paper from the SSSG was considered at the PuWG meetings on 17 and 30 April. The paper was endorsed by the PuWG, along with the following recommendation:

"That the company's assessment of the development requirements of immobilisation options focus on those options without an external radiation barrier. The assessment should, however, examine the feasibility and value of other potential 'intrinsic' security features."

6.2.3 Ease of Separation of Plutonium from MOX

This issue was addressed by the SSSG because of the wide divergence of views that had been expressed in public by different stakeholders. The SSSG examined whether this divergence was more apparent than real. It did this by reviewing technical papers authored by staff at DTI/IAEA[46] and by Frank Barnaby[47].

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[44] Under the 1977 treaty with the IAEA and Euratom, which covers safeguards on fissile materials at Sellafield and other UK licensed sites, it is possible for the Government to withdraw fissile material such as plutonium from safeguards coverage, on grounds of "national security."

[45] These might include a combination of physical and institutional security arrangements, including the physical form of the conditioned plutonium, or for example, making the package massive and difficult to handle (see Annex 5).

[46] G Andrew (International Atomic Energy Agency), T Barrett (Consultant), M Beaman (Department of Trade and Industry) 'Safeguards-Related Consideration of the Conversion of Unirradiated Plutonium in MOX Fuel to Metallic Form', IAEA-SM-367/3/04. The views expressed in this paper are those of the authors and should not be taken as necessarily representing the views or policies of the organisations they are employed by.

[47] F Barnaby, 'Arguments Against the Production and Use of Mixed-Oxide Nuclear Fuel', Oxford Research Group, April 2001.

Initially it was hoped that the SSSG's review would be informed by a peer review of the Barnaby paper by the DTI or IAEA authors. Unfortunately, neither author responded to Frank Barnaby's personal request for such a review. As a result, the SSSG's review was informed by input from the Company's expert adviser to the PuWG.

The SSSG's conclusion is that there is agreement on the types of measures and techniques that would be required to extract plutonium from MOX, but some uncertainty about whether the utilisation of these measures and techniques constitutes a "considerable undertaking". In seeking to establish common ground on this issue, it was agreed that if a State or Sub State group had the necessary technical capability and experience to construct a nuclear explosive device from plutonium, it would almost certainly have the technical capacity to extract plutonium from MOX.

6.3 The Regulatory Framework for Civil Nuclear Security in the UK

Discussion on this issue was informed by publication of the first annual report of the OCNS in June 2002[48]. This report provided important information on the state of security in the UK civil nuclear industry and the effectiveness of security regulation. In particular, it addresses:

- the role of the OCNS
- the nature of threat assessments
- security standards
- security vetting
- OCNS inspections
- the SMP
- the transport of nuclear material
- information security
- response to the events of September 2001
- confidentiality versus transparency.

The SSSG welcomed the fact that more information is being made publicly available about security arrangements[49], but some members expressed the view that the level of information provision was still insufficient.

The SSSG acknowledged that it is legitimate for specific security information to be withheld in the interests of national security and recognised that there is legislation governing disclosure[50]. However, members of the sub-group also wanted to be reassured that the processes of security management by BNFL and its regulation were robust and appropriate to the risks in a post-September 11 world. It therefore decided to engage in discussion with the OCNS. The outcome of this discussion is reported in Section 7.

[48] Director of Civil Nuclear Security, 'The State of Security in the Civil Nuclear Industry', Report to the Secretary of State for Trade and Industry, June 2002 available from DTI website (http://www.dti.gov.uk/energy/nuclear/safety/security.shtml).
[49] United Kingdom Atomic Energy Authority Constabulary (UKAEAC) Police Authority Report 2001/2002 and UKAEAC Chief Constable's Annual Report 2001/02, available from UKAEA Constabulary website (http://www.ukaea.org.uk/ukaeac/reports.htm); The Standing Committee on Police Establishments (SCOPE), A report to the Minister by the Director of Civil Nuclear Security, June 2002, available from DTI website (http://www.dti.gov.uk/energy/nuclear/safety/security.shtml).
[50] BNFL, 'A basic guide to Section 79 of the Anti-terrorism, Crime and Security Act 2001'.

Some members of the sub-group were also concerned that the events of September 11 would lead to greater restrictions on the release of information about the nuclear industry at a time when commitments were being made to greater openness and transparency, particularly in the White Paper 'Managing the Nuclear Legacy'[51]. This concern was increased by the following statement in the OCNS annual report:

".. we recognised after the attacks last September in the United States that the balance between providing information of legitimate public interest and protecting the national interest against terrorism and proliferation may need to be re-considered. I am chairing an expert group composed of representatives from the main operating companies and the industry's regulators to take this forward."[52]

6.4 Future of the SSSG

Although the work of the SSSG has enabled the PuWG to identify some important common ground on the security and safeguards issues associated with plutonium management, the PuWG considers that there is a case for further consideration of security issues within the dialogue process. In particular, this further consideration might encompass:

- discussion about where the boundary between confidentiality and transparency should lie (with specific reference to restructuring of the nuclear industry and the creation of the LMA); and
- the security of the international transport of plutonium materials.

We therefore recommend that the Coordination Group and Main Group ensure that security issues receive further consideration within the Dialogue and decide how this consideration can be best achieved.

[51] DTI, 'Managing the Nuclear Legacy: a Strategy for Action', Cm 5552, July 2002.
[52] Director of Civil Nuclear Security, 'The State of Security in the Civil Nuclear Industry', Report to the Secretary of State for Trade and Industry, May 2002, para 45.

7 Engagement with Wider Stakeholders

7.1 Introduction

This section summarises the outcome of the PuWG's engagement with key stakeholders that were not members of the Group. These stakeholders were:

- The OCNS
- The Decommissioning, Waste Management and Nuclear R&D Division within the DTI[53]
- Nirex.

7.2 OCNS

As explained in Section 6.3, the SSSG decided to engage in discussion with the OCNS to seek reassurance on the robustness of the processes for security management and regulation.

Initially, it was hoped that OCNS could participate in SSSG meetings but OCNS explained that for logistical reasons this had not been possible. The SSSG has therefore had to rely on a written exchange of questions and answers with OCNS (see Annex 6).

The non-availability of the OCNS representative to attend meetings was regretted by the SSSG because face-to-face discussion could, in principle, provide a greater degree of explanation and reassurance than a written exchange.

Nonetheless, the written Q&As did provide opportunity for the SSSG to raise a wide range of security issues with the OCNS. In its responses, the OCNS was able to provide limited factual responses to questions about security accountabilities and regulatory arrangements, but not about the Design Basis Threat[54] or specific security measures. OCNS indicated they were unable to answer questions on the latter topics for reasons of national security.

On balance, the SSSG felt slightly better informed as a result of the written exchange, but the fundamental dilemma remains of how to provide adequate reassurance without prejudicing security. **It has already been recommended that ways of resolving this dilemma might be addressed in a reconvened SSSG (see Section 6.4).**

7.3 Nirex

During 2002, the PuWG became aware of a Nirex Interim Technical Note “Management of Plutonium: Disposal Considerations” which had been prepared at DTI's request. The work was clearly of interest to the PuWG's deliberations.

Nirex advises waste producers on packaging requirements for intermediate-level wastes (that contain nearly 8 tonnes of plutonium) based on its cement-based phased geological disposal concept. Nirex explained that it had drawn on this experience and the underlying safety assessment methodology to identify the implications of declaring all or part of the stockpiles of separated plutonium as waste.

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[53] The Decommissioning, Waste Management and Nuclear R&D Division within the DTI had been represented in the PuWG in the early phases of its work, but this was not continued when a change of personnel occurred within the DTI.

[54] The Design Basis Threat is the analysis of potential threats and capabilities that must be defended against.

PuWG observed that Nirex's Note only dealt with immobilised Pu waste forms incorporating a radiation barrier. Moreover, it only considered two types of matrix - namely conditioned intermediate level radioactive wastes, and glass - for the incorporation of plutonium.

The basis of Nirex's work was clearly different from the conclusions which PuWG had reached within its own terms of reference. The Group had specifically concluded that:

- The addition of a radiation barrier was of questionable benefit to the overall security of the plutonium and there would be merit in examining further if other "intrinsic security" arrangements should apply (see Section 6.2). Clearly, such arrangements - which might include the type of matrix and the type and size of the container used - could in turn bear on the long-term management, including disposal, of the waste.

- In regard to the higher plutonium loading that could be achieved and the better resistance to leaching in repository conditions, ceramic matrices would have advantages over glass.

At PuWG's request, Nirex considered our Interim Reports, draft SAPs and the PuWG Security and Safeguards Subgroup papers. By means of a presentation and discussion at the PuWG meeting on 5-6 June 2002, together with further written submissions, Nirex provided PuWG with an update and expansion of their views on the long-term management, including disposal, of spent MOX fuel and other plutonium waste forms.

The specific questions that PuWG put to Nirex, together with Nirex's responses, are detailed in Annex 7.

Nirex indicated that it would be prepared to undertake further studies on disposal of immobilised plutonium waste forms. PuWG recommends that it should do so and that it should focus on ceramic waste forms (including low spec MOX).

With hindsight, PuWG concluded that Nirex had been brought into the Group's discussions at much too late a stage. Nirex clearly had valuable technical advice and information to offer and we consider that their continued engagement with the Dialogue would be useful.

7.4 Decommissioning, Waste Management and Nuclear R&D Division (DTI)

The PuWG was also aware that the DTI is chairing an Interdepartmental Working Group (IWG) on the management of plutonium. The PuWG considered it important to engage with the DTI so that information could be exchanged about the respective deliberations of the IWG and PuWG. It was anticipated that both groups would benefit from such an exchange.

The PuWG therefore extended a series of invitations to the DTI to attend future meetings. Unfortunately, DTI explained that, due to pressure of work, they were unable to accept this invitation. The DTI has also informed the PuWG that it would not in any case be able to share information about the work of the IWG. The PuWG regrets that the DTI has not been able to respond more positively.

In view of the potential importance of the work of the IWG, the PuWG recommends that the Main Group authorise the PuWG to seek an opportunity to present the findings of this report to a future meeting of the IWG.

8 Findings and recommendations

8.1 Storage of plutonium oxide and drivers for change

Most of the Group consider that current storage arrangements are well established and may be considered adequately safe and secure for the short and medium term - that is, for about the next 25 years. This conclusion is of course conditional on the maintenance of robust security and safeguards arrangements, and also on the maintenance to a high standard of the storage facilities, the repackaging facilities, and all the associated operational procedures.

Equally however, we consider that storage of plutonium as plutonium dioxide powder in its present form does not meet the requirement of ‘passive safety’ for long term storage. Further, in the absence of any clearly foreseen end use for the material, one might expect increasing international pressure for the reduction of stocks of separated reactor grade plutonium. During the course of our work the Government announced that, following consultation on nuclear waste policy, relevant waste management assessments would now proceed for at least some of the plutonium stocks.

For these reasons, we consider an alternative approach to the management of plutonium stocks, in the form of a clearly defined disposition programme, needs to be developed.

We therefore endorse the view, expressed in the Company’s Study, that current storage arrangements can only be viewed as an interim measure and other management options should be underway within a 25 year timeframe.

However, there is concern that the Company’s plans to construct a new plutonium store at Sellafield could lead to the storage of separated plutonium beyond an acceptable timeframe.

In order to provide some boundary on ‘timeliness’, we consider that a ‘timely’ programme for plutonium disposition would not require the construction of any new stores for plutonium oxide, nor any refurbishment or life extension of stores much beyond 2050, except for compelling safety or security reasons.

We feel it is important that any change to the current storage arrangements should be carefully considered through a process which entails stakeholder engagement and be substantiated by a comprehensive analysis covering the short, medium and long terms. This report shows that the analysis will entail significant research, process development and design studies.

8.2 Objectives for the long term management of separated plutonium

We conclude that the end point of any viable option for the management of separated plutonium should be the conversion of plutonium into a ‘passively safe’ form, suitable for long term storage. Most of the group also consider that the converted plutonium should be in a form readily amenable to disposal because this is a management strategy which may ultimately be implemented. However, some of us question the ultimate viability of disposal.

Through the Security and Safeguards Subgroup’s considerations we reached a consensus that the addition of an external radiation barrier to immobilised plutonium was of questionable benefit for assuring the security of BNFL's separated plutonium stocks in the future. We further agreed that any management strategy for BNFL's separated plutonium stocks must provide a very high level of assurance that plutonium cannot be extracted illicitly for use outside the current international non-proliferation regime. This might be achieved through a combination of physical and institutional security arrangements, together with the physical and chemical form of the conditioned plutonium (to make extraction difficult).

The vast majority of the UK plutonium stockpile is civil in origin and there are legal obligations for the material to remain subject to proper safeguards verification. The addition of a radiation barrier would complicate the existing safeguards methods for verifying plutonium oxide or fresh MOX and successful verification would require novel approaches that do not currently exist.

The Company Study also expresses scepticism about the value of adding an external radiation barrier to immobilised plutonium waste forms and highlights the practical difficulties that this would pose for existing verification regimes. This is a further area of common ground.

There is also agreement amongst us on the types of measures and techniques that would be required to extract plutonium from MOX but some disagreement about how “considerable an undertaking” it would be for a state or group that acquired MOX for the purpose of making weapons**.** In seeking to establish common ground on the latter, it was agreed that if a State or Sub State group had the necessary technical capability and experience to construct a nuclear explosive device from plutonium, it would almost certainly have the technical capacity to extract plutonium from MOX.

In order to define the ‘product’ for long term management of separated plutonium, a waste form qualification system needs to be developed relatively promptly (i.e. not be bound up in the longer staged MRWS process on policy for long term management). It should be possible to apply this system to immobilised forms of plutonium, including spent MOX and ‘low spec’ MOX.

8.3 Options for meeting long term management objectives

8.3.1 Broad options considered

We consider that plutonium management options involving transmutation, or novel fuel cycles such as thorium/plutonium fuels, should not be considered as means of dealing with BNFL's current stockpiles of separated plutonium. This is because the technology required is far too immature and the options cannot be implemented within the timescale which we consider appropriate (that is, around 25 years).

Although recognising the opposition of some members of the group to the use of plutonium as a reactor fuel (see disclaimer in Foreword), we agreed that there should be further assessment of the following broad options:

- Immobilisation,
- Immobilisation with an added radiological barrier
- Use as Mixed Oxide or Inert Matrix fuel.

8.3.2 Immobilisation options

We consider that options involving direct immobilisation of plutonium in glass should be excluded from further consideration because available studies indicate that ceramic waste forms are superior should disposal ultimately be chosen. In addition, there are process safety issues relating to criticality and worker dose for the glass-based options.

The Company study concludes that ceramic waste forms are preferred over vitrified glass. It adds that: “unless a major breakthrough is made internationally, BNFL does not plan to sanction development work on the direct incorporation of plutonium dioxide into glass as a method of immobilisation.” We welcome this finding, which supports and strengthens our initial conclusions above.

We conclude that the principal uncertainties associated with the immobilisation options are the specification of the optimum product and - for purpose-designed ceramics - the lack of demonstrated processes at the industrial scale to deal with the required quantities of plutonium oxide. Whilst recognising that development requirements for a new plant would be considerable, we note that there appear to be no fundamental obstacles to developing the necessary products and processes.

The Company Study reports on a 5 year collaborative research programme with the University of Cambridge, which is examining the use of synthetic mineral analogues as host phases for actinides and plutonium. We welcome this programme, which provides an opportunity to carry forward important research in this area.

However, many of us are disappointed that the Company has not given more consideration to the low spec MOX option in its study, and consider that the option has been dismissed too lightly. There is concern that the option has been rejected on policy grounds, rather than as a result of a systematic appraisal of immobilisation options, and a feeling that further evaluation is needed to establish whether the low spec MOX option can be viewed as a viable contingency.

We welcome the acknowledgement in the Company Study that immobilisation is a likely candidate for part of the stockpile but note that that the study does not provide sufficient information and analysis to justify the conclusion that this should apply to only around 5% of the stockpile.

Many of us are disappointed that the Company Study was unable, as had originally been intended, to provide even any broad estimates of the cost for developing and implementing the immobilisation options for separated plutonium.

8.3.3 Reactor options

In contrast to immobilisation, which has not been established on an industrial scale, the commercial use of MOX fuel has been established in some light water reactors in four European countries - Belgium, France, Germany and Switzerland[55].

The Company Study concludes that use of MOX fuel in Sizewell B is practicable and could in principle use about a third of the current plutonium stockpile over its lifetime. However Magnox reactors do not present a viable option and the AGRs present a number of practical difficulties. These conclusions are in agreement with the results of our own analysis.

There is also agreement in principle that if current technical, regulatory and commercial hurdles could be overcome, existing UK reactors - specifically Sizewell B, Heysham 2 and Torness - could use a substantial fraction of the original stockpile. However, to use all of the stockpile within a reasonable time (by around 2050) it is likely that availability by about 2015 of one or two new reactors similar to the AP1000 type would be required.

The Company Study supports the use of the plutonium stockpile as MOX in this way. However, many of us are concerned that this conclusion is not adequately supported by the analysis presented in the study. Particular concern surrounds the basis on which generation costs have been estimated, uncertainties about the financial and commercial arrangements on which new reactors would be constructed and uncertainties associated with Government energy policy, planning and regulatory requirements which represent significant hurdles to new build reactor developments.

For these reasons, many of us consider that the Company appears to be placing an excessive emphasis on a plutonium management route, involving the use of MOX fuel in new build reactors, that may not come to fruition.

[55] 35 of the 81 reactors in these countries have used MOX fuel.

8.3.4 Keeping options open

For the reasons indicated above, we consider that there is a need to keep options open at this stage, particularly in the light of the uncertainties attendant on all the options so far identified.

8.4 Recommendations on the explorations required to reach an informed decision on the management of separated plutonium

These recommendations comprise our views on the explorations necessary to reach an informed decision on the future management of separated plutonium. They should not be read as advocating any of the individual options, or as assuming that any of the options will proceed.

As noted in the disclaimer, some members remain opposed to further plutonium separation, the production and use of MOX as fuel or for any other purpose, including immobilisation, or the construction of new nuclear power stations on various grounds including their concerns on safety, environmental and proliferation issues.

Because of the proposal to establish a Liabilities Management Authority (LMA) and the expectation that ownership of BNFL's UK plutonium will pass to it in 2004/5, where appropriate these recommendations are addressed to the 'plutonium owner'. In the first instance, we would look to BNFL for a response but we would also commend these recommendations to the LMA on its formation and ask that it should consider the recommendations and BNFL's response up to that time in deciding its strategy for the management of separated plutonium.

We consider all of the recommendations which follow to be inter-connected and all are necessary to arrive at well informed decisions about the long term management of separated plutonium. They should not be selectively implemented.

1. We recommend DEFRA should take the lead in establishing a waste form qualification system, which can be applied to the potential plutonium waste forms, as a matter of urgency, taking into account the work currently being done for intermediate level wastes by HSE, SEPA and EA.

2. We recommend that the 'Pu owner' should ensure that the development of detailed proposals for the management of separated plutonium and the associated decision making, should incorporate stakeholder engagement as an integral part of the process. Where appropriate, this should extend to the associated investigations.

3. We recommend that the 'Pu owner' should disregard use of MOX in the Dungeness B, Hunterston B, Hinkley B, Hartlepool and Heysham 1 reactors as useful options for the management of separated Pu.

4. We recommend that, in the interests of fully establishing the practicability or otherwise of using MOX fuel in Sizewell B, Heysham 2 and Torness, and before any decisions on implementation are taken:

   - The Pu owner and BE (as the 'Pu user') should enter into initial discussions to explore the financial basis for this option (NB This recommendation may change depending on outcome of current restructuring of BE).

   - The availability of capacity in SMP should be reviewed, taking account of both the duration and timing of fulfilling contract commitments to overseas customers and the feasibility of a life extension for the plant.

- Should these explorations indicate that using Pu in Sizewell B or either of the AGRs may be attractive from a liability management point of view for both parties, we recommend that the Pu owner and the Pu user should undertake a comprehensive environmental impact assessment (EIA) on the proposal including the evaluation of transport, reactor safety (including the risks resulting from extreme core disruption events), environmental discharge, public safety, and waste form storage issues. This assessment should be conducted in consultation with stakeholders at national and local levels.

5. To explore the feasibility or otherwise of utilising plutonium, in the event that any programme of new build reactors were to proceed, we recommend that before any decisions are taken:

   - The financial basis on which Pu might be utilised in new build reactors should be explored at an early stage between the Pu owner and the likely developer for any new build reactors. The existing collaborative agreement on new build between BNFL and BE may be a suitable vehicle for this.
   - The availability of capacity in SMP should be reviewed, taking account of the feasibility of a life extension for the plant.
   - Should these explorations (and the outcome of the energy review) be favourable to Pu use in new build, we recommend that the prospective developer should undertake a comprehensive environmental impact assessment (EIA) on the proposal including the evaluation of transport, reactor safety (including the risks resulting from extreme core disruption events), environmental discharge, and wasteform storage issues. This assessment should be conducted in consultation with stakeholders at national and local levels.
   - A detailed comparison of MOX, IMF and conventional uranium fuel should be undertaken prior to deciding which fuel type to use.

6. In the light of long lead times, we recommend that the Pu owner commits promptly to an immobilisation research, process development and design study to more fully establish the optimum technology for plutonium immobilisation. This should include:

- Underpinning research on ceramic immobilisation matrices
- Consideration of possible Pu loadings, inclusion of neutron absorbers, safety and safeguards requirements
- Assessment of possible product forms against waste specification requirements
- Design studies for process optimisation
- Consideration of low spec MOX as an immobilised Pu product
- A BPEO analysis, conducted with stakeholder involvement, which brings together findings of the above in order to establish the optimum process and waste form.
- A comprehensive environmental impact assessment (EIA) on the proposal including the evaluation of plant safety, environmental discharge, and waste form storage issues. This assessment should be conducted in consultation with stakeholders at national and local levels.

The aim should be to make sure that immobilisation can be made available within the period suggested by our timeline in Figure 1, and that the merits or otherwise of this approach can be taken properly into account before decisions about plutonium management are made.

7. In order to ensure the option of using SMP immobilised Pu as low-spec MOX is not foreclosed, we recommend that the Pu owner should, before final decisions about plutonium management are made:

- Undertake a more detailed assessment of the suitability of low spec MOX as a form of immobilised Pu product, including consideration of security, safety, safeguards, waste form qualification and other relevant issues.

- Undertake a design study to establish whether SMP could feasibly be modified to produce a more ‘optimised’ Pu wasteform, either in current or newly added production lines.

- Review the use of SMP in the light of the above investigations and those on the other options as recommended above, once the future contractual commitments of SMP for overseas and domestic customers become clearer.

- Include the ‘SMP option’ in the BPEO for immobilisation options recommended in respect of new build plant.

- Assess the findings of this investigation programme as part of the regular review of SMP operation alluded to in the White Paper ‘Managing the Nuclear Legacy’.

8. We recommend that research and process development for plutonium immobilisation should concentrate on those options which do not involve an added external radiation barrier; however other means of increasing the intrinsic security of the product should be explored.

9. At this stage, we consider that it is important to keep options open so that contingencies are available for each of the plutonium disposition options. In order to ensure this we recommend that:

- All the actions and explorations indicated above should be carried out to the point at which the Pu owner can make informed decisions (with stakeholder involvement) on the contribution each option should make to management of the plutonium stockpile.

- In reaching these decisions, consideration should be given to: maintenance of contingency in the longer term, community views on the long term storage onsite of Pu waste forms, socio-economic factors including employment, and the impact of Pu stockpile management options on the wider Sellafield clean-up programme

- The Pu owner should then develop a more detailed plan which shows how the options could be used to convert the current and projected future stockpile of separated Pu into a passively safe form suitable for very long term storage and, potentially, ultimate disposal.

- Such a plan should aim to achieve conversion to a timescale which would render construction of new Pu oxide stores, or refurbishment of existing stores unnecessary, except for compelling safety or security reasons.

8.5 Recommendations to, and requests of, the Main Group

1. We commend this report to the Main Group as completion of the work of the PuWG.
2. We recommend that the Main Group should ask the Company to formally consider and respond to the recommendations in this report (see Sections 4, 5 and 8.4).
3. We recommend that the Main Group should invite the Business Futures Group to monitor the Company's response to the recommendations in our report and make further recommendations as appropriate.
4. We recommend that the Coordination Group and Main Group ensure that security issues receive further consideration within the Dialogue, and decide how this consideration can be best achieved.
5. We recommend that the Main Group should ask the Coordination Group to discuss possible solutions to the problem of lack of information provision about costs and report back to a future Main Group meeting.
6. We recommend that the Main Group should encourage working groups to give careful consideration to the pros and cons of different models for undertaking detailed studies before deciding which one to adopt; to have realistic expectations about the potential for, and value of, detailed Multi-Attribute Decision Analyses; and to consider whether a SAP analysis should be undertaken first, so that the scope and priorities of the study are informed by SAP findings.
7. We recommend that the Main Group should encourage working groups to engage directly with relevant stakeholders outside their membership.
8. We recommend that the Main Group should authorise publication of this report through The Environment Council as soon as practicable, subject to incorporation in the report of any comments they have.
9. We recommend that the Main Group should authorise the Plutonium Working Group to seek an opportunity to present the findings of this report to a future meeting of the DTI Inter-Departmental Working Group (IWG) on plutonium management.

Annex 1: PuWG membership March 2002 - October 2002

The Working Group members at the time this report was drafted and finalised were:

Arthur Roberts	BNFL
Brian White	Copeland Borough Council
Chris Wright	General & Municipal Boiler Maker's Union (GMB)
Clive Williams	Environment Agency
Dave Andrews	Campaign for Nuclear Disarmament
David Lowry	Independent consultant[1]
Dick Haworth	Nuclear Installations Inspectorate
Frank Barnaby	Oxford Research Group
Fred Barker	Nuclear policy analyst[2]
Howard Rooms	National Campaign for the Nuclear Industry
Mark Drulia	BNFL
Paul Leventhal	Nuclear Control Institute
Roger Howsley	BNFL
Steve Jones	Westlakes Research Institute
Sue Wilkinson	British Energy

Earlier members of the Working Group were:

Rachel Western	Friends of the Earth
Shaun Burnie	Greenpeace International
Nigel Chamberlain	CND
Bill Turner	British Energy
Tony Free	British Energy
David Mason	Nuclear Installations Inspectorate
Robert Gunn	Department of Trade and Industry

These earlier members left the PuWG for a variety of reasons - including illness, a change of duties, and withdrawal of their organisation from the Dialogue.

[1] Dr David Lowry provides research support to one Labour MP and one Irish Green MEP on nuclear issues, and has been a contributing editor to the periodic report ‘Plutonium Investigation’ published by WISE-Paris.

[2] Fred Barker’s participation in the PuWG is sponsored by the Nuclear Free Local Authorities Steering Committee.

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Annex 2: Background Information on Current Status of UK Civil Plutonium Stocks; Options for Management

A.2.1 UK plutonium stocks and arisings

A.2.1.1 Production and properties of plutonium

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

These reactions produce a number of different ‘isotopes’ of plutonium. The principal isotopes in spent fuel from nuclear reactors are plutonium-238, plutonium-239, plutonium-240, plutonium-241 and plutonium-242. Trace quantities of plutonium-236 are also present, and these may be of some significance in radiation dose rate calculations. Like uranium-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. However, only plutonium-239 and plutonium-241 are fissile in the thermal neutron fluxes of conventional water-cooled or gas-cooled nuclear power reactors.

Plutonium dedicated for weapons manufacture has been produced in the UK, as it has elsewhere by states which maintain a nuclear weapons capability[1]. Plutonium for weapons manufacture is normally produced in such a way as to minimise the content of the even-numbered isotopes which undergo spontaneous fission. It may be produced, for example, by irradiating uranium fuel in a thermal reactor for only a relatively short period of time. Material produced in such a way is referred to as 'weapons grade' plutonium and typically contains greater than about 93% by weight of plutonium-239 and less than about 7% plutonium-240[2].

When plutonium is produced as a by-product of energy generation in uranium fuelled reactors, the uranium fuel is left in the reactor for a longer time to maximise the amount of energy extracted (the 'burn-up'). This results in the production of a much higher proportion of the even-numbered isotopes of plutonium. Plutonium produced in Magnox reactor fuels typically contains up to about 70% of plutonium-239 by weight, whereas plutonium produced in light water reactor fuels (which achieve higher burn-up of uranium) would typically contain about 50% of plutonium-239 by weight. Plutonium produced in this way is referred to as 'reactor grade' plutonium. Reactor grade plutonium can be utilised as a fuel for energy generation, but it would not be the material which an advanced nuclear weapons State would normally choose to use for weapons purposes.

Notwithstanding the lower attraction of reactor grade plutonium to weapons designers, it could be used to construct an explosive device, and this has been done for test purposes by the UK and US[3]. The weapons-usability of reactor grade plutonium is accepted by the international safeguards community and by the UK Government[4]. Accordingly, all UK reactor grade plutonium is subjected to security and safeguards to deter state diversion or acquisition by sub-national groups.

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[1] Some of these states additionally, or alternatively, use highly enriched uranium.
[2] Royal Society, ‘Management of Separated Plutonium’, February 1998.
[3] Arnold L, ‘A Very Special Relationship: British Atomic Weapon Tests’, Ch 4, HMSO. Some members of the group believe that reactor grade plutonium could be regarded as having advantages over weapons grade plutonium, as it does not require a separate neutron source in order to achieve a nuclear explosive yield (M Bunn, ‘The US Program for Disposition of Excess Weapons Plutonium’, paper to IAEA Conference, June 1997).
[4] Gilbert, Lord, Minister of State, Ministry of Defence, House of Lords, Hansard, 24 July 1997, Col WA 184.

A.2.1.2 UK stocks and arisings of separated plutonium

The first step in making plutonium accessible for use in manufacture of either fresh nuclear fuel or nuclear weapons is its chemical separation from the irradiated nuclear fuel within which it was produced. This chemical separation process is relatively straightforward in principle, but in practice the highly radioactive nature of irradiated fuel makes this a complex and expensive undertaking. Thus, the plutonium content of spent nuclear fuel is considered to be relatively secure against diversion for weapons use. Indeed, the US and Russia, in considering the disposition of excess military weapons grade plutonium, have developed the concept of the 'spent fuel standard' as a benchmark for the difficulty of diversion of plutonium[5]. Thus, the management of stocks of plutonium which have been separated from spent nuclear fuel raise particularly important issues for consideration.

Since the commissioning of the Magnox reactors for power generation in the early 1960s, the UK strategy for the management of spent nuclear fuel has been dominated by reprocessing, with the separated plutonium being viewed as a potential energy source, and stored and regarded as an asset. However this view of plutonium has been increasingly questioned since the early 1990s, when the UK Government decided to phase out all support for the development of 'fast reactors', which had been central to the initially envisaged strategy for the long term utilisation of civil separated plutonium.

As a consequence of the current spent fuel management strategy, the UK currently has significant stocks of separated reactor grade plutonium, which are held in stores under international safeguards at Sellafield. Since the merger of BNFL and Magnox Electric, the majority of this material (which originates from the Magnox reactor programme) is owned by BNFL. Lesser quantities are owned by British Energy, the UKAEA, the Ministry of Defence, and BNFL's overseas customers.

Figures for the UK stocks of plutonium are published annually by the Department of Trade and Industry and a perspective on future arisings has been given by the Royal Society[6]. BNFL has provided information on the Sellafield component of the UK stocks (small quantities are held by the UKAEA).

[5] US Department of Energy, ‘Record of Decision for the Surplus Plutonium Disposition Final Environmental Impact Statement’, January 2000.
[6] Royal Society, ‘Management of Separated Plutonium’, February 1998.

The breakdown of separated plutonium stocks at Sellafield is as follows:

TABLE A.2.1: SEPARATED PLUTONIUM STOCKS HELD AT SELLAFIELD (Te)				
Date	BNFL	Other UK	Overseas Customers	TOTAL
December 2001	54.8	8.4	16.7	79.9
Projected from contractual commitments to reprocessing	77	27	37	142

Notes:
1 BNFL stocks are taken to be total Magnox stocks less Magnox stocks owned by overseas customers.
2 Other UK stocks are primarily those arising from the reprocessing of AGR spent fuel.[7]
3 The stocks belonging to overseas customers arise mainly from reprocessing in THORP. A small proportion also arises from Magnox reprocessing.
4 The projected figures are approximate and subject to change
5 For the purposes of comparison, the critical mass of reactor grade plutonium is 13 kilograms for a bare metal sphere.

Projected figures assume completion of the Magnox and AGR reprocessing programmes envisaged by BNFL. They do not include any separated Pu from the Sizewell PWR, since there are no plans currently for that fuel to be reprocessed. The quantity of plutonium from overseas customers will ultimately depend both on the quantity of fuel reprocessed and the quantity returned to customers, whether as Mixed Oxide fuel (MOX) or in any other form. Most of BNFL's reprocessing contracts with overseas customers allow for the ultimate return of separated plutonium, subject to UK and international requirements.

A.2.1.3 Current arrangements for the storage of separated plutonium

Plutonium stocks at Sellafield are held in the form of plutonium dioxide powder. This form is in principle suitable for direct incorporation into Mixed Oxide fuel. The stores are built specifically for the purpose and provide a number of physical, procedural, and security barriers intended to prevent unauthorised access to the material. The stores are subject to international safeguards inspection under the auspices of the IAEA and Euratom. Some members of the Group pointed out that the degree to which the material is actively safeguarded is not made public. They consider that the effectiveness of the safeguards regime is open to question.

In addition to security of the material, the design of the stores takes into account a number of potential hazards associated with the handling and storage of plutonium in large quantities[8].

[7] As a result of the 1998 Strategic Defence Review, the MOD has declared 4.1 tonnes of plutonium stored at Sellafield surplus to military requirement, along with a further 0.3 t of weapons grade plutonium in oxide form at Aldermaston. All of the separated plutonium at Sellafield is under safeguards, and the remainder is being progressively moved to Sellafield, where it is placed under safeguards. These quantities are not included in the figures in Table 1.

[8] Leigh B, ‘Plutonium dioxide - A managed resource for the present and the future’, Proceedings of Global 95 - International Conference on Evaluation of Emerging Nuclear Fuel Cycle Systems, Versailles, September 1995.

1 Criticality: Plutonium, in common with other fissionable materials, can undergo an uncontrolled nuclear chain reaction if too much of the material is brought close together under the wrong circumstances. Such unintended chain reactions are usually short-lived and the energy releases small; nonetheless, very high levels of radiation are produced which can be fatal to anyone in the near vicinity of the reaction. The plutonium is stored in stainless steel cans, each containing less than the 'critical mass' and the design of the store physically prevents the cans being placed too close together.

2 Radiotoxicity: Most of the plutonium isotopes emit alpha radiation and are very hazardous if inhaled or ingested. Plants which process plutonium need to provide a high degree of 'containment' to prevent contamination of the working areas with plutonium containing dusts; in the stores, the plutonium oxide powder is sealed inside a series of cans. The current Magnox stores utilise an inner aluminium screw-top bottle surrounded by a polythene wrapper, all contained within a seamless stainless steel can with a welded lid. The Thorp stores utilise a triple stainless steel can system. Instrumentation within the stores monitors continuously for any release of radioactivity. The earlier Magnox stores (prior to the early 1980s) have used a variety of plutonium can and bottle designs which included PVC plastic liners; these designs were not suitable for long term storage and re-canning has been necessary (see below).

3 Heat generation: Radioactive decay of the stored plutonium generates a significant amount of heat. Heat is removed from the cans by convection, but forced ventilation is required to provide sufficient airflow through the stores and allow acceptable can temperatures to be maintained. The ventilation systems are designed with 'redundancy' - there is more fan capacity than is needed, separate inlet and extract fans are provided, and standby power supplies are available.

4 Deterioration of packaging: Plutonium dioxide powder readily absorbs moisture and even some gases from the atmosphere; these can be released during storage causing pressure to build up in the can. Over a long period of time, the intense alpha radiation from the stored plutonium also results in the build up of helium gas within the can. In addition, the PVC present in pre-1980 Magnox can designs suffers from radiation induced deterioration. In the post-1980s stores, attention to product quality together with the package design results in a nominal 50 year lifetime for the packages. The material in the pre-1980 cans has required repackaging. A repackaging plant is provided, both for the older material and as a contingency for current package designs. A randomly selected sample of packages are examined each year using both destructive and non-destructive techniques. This programme is intended to ensure that any package deterioration is detected before it becomes problematic.

5 Ingrowth of americium-241: The alpha radiation emitted by stored plutonium is entirely absorbed by the packaging material. Thus, whilst the plutonium is potentially very hazardous if it escapes from the can and becomes ingested or inhaled, the canned plutonium can be handled safely without the use of heavy radiation shielding. However, radioactive decay of the isotope plutonium-241 produces the isotope americium-241. In addition to emitting alpha radiation, americium-241 also emits more penetrating low energy gamma radiation. Over a period of time, levels of gamma radiation from the stored cans increase. Eventually, the handling of the stored plutonium, whether for repackaging, conversion into mixed oxide fuel, or conversion into some other stable form for long term storage, would require either substantial radiation shielding or, ultimately, inclusion of an additional process step to chemically separate the americium-241 from the plutonium. BNFL advised us that such steps would be required after about 55-60 years for storage of plutonium derived from Magnox fuel, or about 10-15 years for storage of plutonium derived from advanced gas cooled reactor fuels.

A.2.1.4 International safeguards and peaceful use

Euratom and IAEA safeguards are applied to plutonium and other nuclear materials in the UK according to the terms of the Euratom Treaty and of a trilateral safeguards agreement with the IAEA and Euratom (the so-called voluntary offer safeguards agreement). These agreements require the UK to place civil nuclear material, i.e. nuclear material that is not designated for national security purposes, under safeguards. Whilst the UK can subsequently withdraw material from safeguards for reasons of national security, the announcement in July 1998 of the outcome of the Strategic Defence Review (SDR) included a commitment that future withdrawals of material from safeguards would be 'limited to small quantities of materials not suitable for explosive purposes'.

Detailed information on withdrawals from safeguards has since been made public[9] and shows, amongst other things, that:

- there have been 11 withdrawal notifications for plutonium in more than gram quantities since the voluntary offer safeguards agreement entered force in 1978. In each of these cases the withdrawal was part of a transaction which did not involve the net transfer of plutonium from safeguards;
- some of the withdrawal notifications involved military-origin material temporarily brought into safeguards at civil facilities and then subsequently withdrawn. Excluding such activities, the notifications for the permanent withdrawal from safeguards of plutonium have involved a total of less than 10 grams of material;
- those withdrawals that have taken place in recent years comprised small quantities of material for use in instrument calibration or radiation detectors, or as analytical tracers (i.e. withdrawals of the kind described in announcement of the SDR).

A.2.1.5 Plutonium accountancy and ownership

After plutonium dioxide powder is placed in specially designed storage containers (cans) the quantity of plutonium is determined using accurate weighing and analytical techniques. This quantity, to the nearest gram, is formally declared to Euratom Safeguards, who pass the information on to the IAEA. Euratom independently verifies the quantity of the material in the can. For most material, including all material from Thorp, the IAEA also verifies the can contents.

Every sealed plutonium can is tracked throughout its life and the location of all cans is known at all times. When material is moved into or out of a major store or group of stores, this is formally declared to Euratom, who pass the information on to the IAEA. Euratom uses various techniques to keep the plutonium stores under surveillance to ensure that they find out independently about any movements of material to or from the plutonium stores. Euratom uses this information to independently verify the information that BNFL provides them on the movements of cans. For most material, including all material placed in the Thorp store, the IAEA also does this.

[9] See Hansard, 2 December 2002, Column 508W. A paper containing detailed information on advance notifications of the withdrawals up to the end of 1999 was placed in the House of Commons Library on 28 July 2000. Information on the notifications during the period Jan 2000 to Feb 2001 was given in a written answer on 1 March 2001 (Official report, Col 732-33W), and information covering the period Feb to Dec 2001 is available on the non-proliferation section of the DTI website (www.dti.gov.uk/non-proliferation).

The ownership accounting system for plutonium has similarities to the operation of a bank. In the case of a bank, different customers deposit money and are given a statement of their account by the bank. The bank does not and could not keep track of everyone's individual notes and coins whilst it is in their system. Similarly, reprocessing customers deliver spent fuel containing plutonium. The amount of plutonium delivered and reprocessed is recorded. Customers retain ownership of this quantity of plutonium which forms their account but, for obvious reasons, individual atoms cannot be traced on a customer by customer basis. When a customer wants to remove a quantity of plutonium from their account, for example for MOX fuel manufacture, specific cans are removed from the store. The allocation method also ensures that if the plutonium sent for reprocessing had international obligations attached to it, then these obligations remain with the material provided back to the customer.

If the customers request any ownership "swaps" or "loans", these may be performed only with the approval of the Euratom Supply Agency, in accordance with the equivalence criteria for such arrangements as defined under European legislation[10]. These equivalence criteria are designed to ensure that "swaps" or "loans" fall within comparable fissile content bands and so disallow the exchange of 'reactor' grade plutonium for 'weapons' grade plutonium or *vice versa*.

A. 2.2 Broad definition of options for plutonium management

We grouped the options for management of separated plutonium into the following broad classes:

1 Transmutation: The use of nuclear reactors or particle accelerators to destroy plutonium by inducing controlled fission reactions. In this case the end product would be rather like an irradiated nuclear fuel element, containing highly radioactive fission products but no uranium and (depending on the efficiency of the process) little plutonium.

2 Immobilisation: Conversion of the plutonium oxide powder into a 'passively safe' form as a waste. Possible immobilised forms include glasses and various ceramics (including forms similar to Mixed Oxide fuel). In this case the end product for storage or disposal would be the immobilised form of plutonium inside a container of stainless steel or similar corrosion resistant material.

3 Immobilisation with a radiological barrier: Immobilisation as above, but with the addition of highly radioactive material (e.g high level waste derived from the reprocessing of spent fuel) to provide a radiological barrier, making illicit access to the plutonium more difficult and dangerous. Variants of this concept include homogenous vitrification (where the plutonium is intimately mixed with glass and high level waste), can-in-canister (where immobilised plutonium cans or pins are placed in a container and surrounded by vitrified high level waste) and spent fuel barrier (where immobilised plutonium cans or pins are placed in a container with irradiated spent fuel pins). In this case the end product is a composite package giving off very high levels of penetrating gamma radiation.

4 Use of plutonium in Mixed Oxide fuels: Fabrication of the plutonium into mixed oxide fuel, with subsequent use to generate energy in a suitable nuclear reactor. Variants of this option reflect the different reactor types: Magnox, Advanced Gas Cooled reactors, existing Light Water Reactor designs, new Light Water Reactor designs, or fast reactors. In this case the end product is spent MOX fuel giving off very high levels of penetrating gamma radiation, and this would possibly be suitable as a final waste product.

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[10] The PuWG was informed by BNFL that the equivalence criteria were part of the administrative arrangements of the US Euratom Nuclear Co-operation Agreement 1995 and that neither the European Commission nor the US Government make these arrangements public. Many members of the PuWG are concerned that the details of these criteria are not publicly available and that it is not therefore possible to demonstrate that the stated objectives are achieved in practice.

5 Use of plutonium in Inert Matrix fuels: A possible new development involves 'inert matrix' fuel, which contains no uranium and in which plutonium is the only fissionable component. This type of fuel would be optimised for 'burning' of plutonium[11]. As for Option 4, the end product is spent ‘inert matrix’ fuel, which also gives off high levels of penetrating gamma radiation.

6 Other uses of plutonium: Other uses of plutonium have been suggested, for example the use of mixed plutonium/thorium fuels in a cycle which produces fissionable uranium-233 from non-fissionable thorium-232. Such cycles are largely at the concept stage, but so far as the end result in terms of plutonium management is concerned, they are not dissimilar to the use of plutonium in Mixed Oxide fuel.

[11] As with transmutation, this option has the potential to actually 'destroy' plutonium, converting it into radioactive fission products. However, Mixed Oxide fuel also contains uranium, so additional plutonium is produced as the original plutonium is burnt. The balance between production and 'burning' of plutonium depends on details of the fuel composition and operating conditions in the reactor.

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BNFL National Stakeholder Dialogue : Plutonium Working Group

Annex 3: An Assessment of the Options for Disposition of the UK Plutonium Stockpile

10 September 2002

2nd DRAFT

It is important to note that, since the PuWG began its work, the UK Government has announced its intention to set up a Liabilities Management Authority which will take legal and financial responsibility for the nuclear materials held at Sellafield except for those owned by BNFL's commercial customers. This will clearly have an impact on how decisions are made (and who makes them) on the future management of the UK Pu stockpile, which includes the plutonium considered in this report and discussed by the WG itself. The final decision will clearly not be made by BNFL; BNFL will however continue to have a role as a stakeholder in this area.

Executive Summary

The purpose of this paper is to present to the PuWG, and hence to the Main Group, BNFL's view of the options for the disposition of the UK Pu stockpile, taking into account the recommendations made by the PuWG over the last 18 months as the work programme has progressed.

At the moment there are approximately 60 metric tonnes of UK separated Pu stored at Sellafield. Arisings from projected Magnox and AGR reprocessing will continue to increase these stocks to around 100 to 105 metric tonnes over the next 10 years (80 metric tonnes Magnox and about 25 metric tonnes British Energy (BE) AGR).

There are three basic options for managing the UK Pu stockpile :

- continued storage as a zero value asset against future use
- immobilisation as waste for long-term and/or indefinite storage then disposal
- recycle as MOX fuel in reactors followed by spent fuel management

Within these main categories there are several sub-options. These have all been considered in detail against a set of appropriate criteria.

Summary of storage option key points

- continued storage is an acceptably safe, secure and safeguarded option for the near future
- storage cannot not be viewed as a viable long-term solution (beyond around 25 years)
- existing and planned stores at Sellafield do not preclude any Pu management option (immobilisation or recycle) from being pursued in the future

Summary of immobilisation option key points

- immobilisation is a likely candidate for a part of the UK stockpile for which technically feasible, but costly, pre-treatment prior to MOX manufacture would be required
- technical and economic uncertainties associated with the relative immaturity of the various immobilisation options mean that immobilisation cannot yet be viewed as an acceptable long-term solution for the rest of the UK stockpile without a significant development programme
- the American can-in-canister concept has not been pursued as part of this investigation because it was deemed unlikely that large quantities of HAL/VHLW would be available for backfilling the canisters on the timescales required for a 'late immobilisation' strategy
- BNFL and the PuWG agree that the ceramic immobilisation option is preferred over the vitrification option and, unless a major breakthrough is made internationally, BNFL does not plan to sanction development work on the direct incorporation of PuO_2 into glass as a method of immobilisation
- BNFL has embarked on significant funding of collaborative programmes with the Universities of Cambridge and Sheffield in order to gain a better understanding of the underpinning technologies for immobilisation techniques

Summary of reactor recycle option key points

- MOX fuel in reactor provides an intrinsic level of immobilisation and also has the benefit of yielding energy from the Pu with the associated revenue offsetting costs
- MOX fuel represents a mature technology. MOX fuel is already loaded and operating well in several reactors in Europe
- although some of the UK Pu stockpile may require treatment it is expected that the greater part of the plutonium held can be fabricated into MOX fuel
- considering the use of MOX fuel in the current UK operating reactors, Magnox reactors do not represent a viable option, AGRs present a number of practical difficulties and Sizewell 'B' could use about a third of the current stockpile over its lifetime
- of the future systems, the AP600 or AP1000 both represent viable options; 2 AP1000 reactors could consume the current UK stockpile over a period of around 20 years
- generating costs will typically be in the range of 2.2p to 3.0 p/kWh
- the utilisation of MOX fuel in a reactor, compared with the use of UO_2 fuel, makes virtually no difference to the overall generating cost of the electricity produced

Based on the work carried out so far, BNFL supports the option of recycling the majority of the UK stockpile as MOX fuel in reactors, in conjunction with the adoption of a policy of new reactor build in the UK. A part of the UK stockpile may be more effectively dealt with by immobilisation and BNFL continues to support investigations, both internally and through funding of University research programmes, into the most appropriate immobilised form.

In addition, BNFL believes that there is much potential in pursuing the inert matrix fuel route. This option involves the manufacture of fuel by incorporating the Pu in an inert (non-uranic) matrix such that the energy of the Pu can be utilised in reactor without creating more Pu. The possibilities which the inert matrix fuel option may offer in terms of immobilisation, stockpile reduction, energy output and revenue earning are encouraging and will be pursued further.

1. Introduction

The BNFL National Stakeholder Dialogue was established late in 1998 with the overall objective of making recommendations to BNFL on ways of improving its environmental performance. As part of this exercise, several Working Groups were convened and asked to report back to the Main Group. The Plutonium Working Group (PuWG) presented an interim report to the Main Group on 23/24 November 2000 [1] summarising its work to date. In that report the Working Group detailed its findings and made recommendations in the context of its focus on the management of stocks of separated plutonium (Pu) owned by BNFL.

Recommendations 8 and 9 of that report state that:

Rec 8 "Our limited analysis indicates that a range of options spanning immobilisation of plutonium in ceramic form, with or without the addition of a radiological barrier, and the use of plutonium as a fuel in existing or advanced light water reactor designs, merit further investigation as long term management strategies for BNFL's plutonium stocks, although strongly held differences of opinion remain within the PuWG on their relative pros and cons. More information on all criteria, especially business viability and safety and environmental performance, would be necessary to make clearer choices between the remaining options."

Rec 9 "We recommend that BNFL should promptly produce proposals for generating such information and for analysis covering all criteria. In doing so, BNFL should have full regard to information which is available from international plutonium disposition programmes, especially immobilisation. These proposals should identify the work that must be done, and give an indication of timescales"

BNFL presented its proposals for further work to the PuWG in December 2000 and gave a brief update on progress in April 2001 [2].

The purpose of this paper is to present to the PuWG, and hence to the Main Group, BNFL's view of the options for the disposition of the UK Pu stockpile, taking into account the recommendations made by the PuWG over the last 18 months as the work programme has progressed.

2. Current situation

At the moment there are approximately 60 metric tonnes of UK separated Pu stored at Sellafield. Arisings from projected Magnox and AGR reprocessing will continue to increase these stocks to around 100 to 105 metric tonnes over the next 10 years [3] (80 metric tonnes Magnox and about 25 metric tonnes British Energy (BE) AGR).

Current UK Government policy, and that of BNFL, is that Pu is an asset; it is 'energy in the bank' [4]. Because of the present UK strategy, however, under which the fast reactor programme has been terminated and with no plans existing to utilise Pu in the fleet of UK thermal reactors, this asset currently has zero value. Nevertheless, the Pu is currently stored safely, securely and under safeguarded conditions in the expectation that it will, at some point in the future, be used as fuel to yield energy in some reactor system.

This policy has short-term operational and long-term strategic implications. In the short term, sufficient storage space must be available to accommodate fresh arisings from reprocessing as well as any residues produced during the manufacture of MOX fuel. Such issues are not the concern of this paper.

For the longer term, BNFL has, over the last few years, kept a watching brief on international developments regarding alternative Pu management strategies. In particular, over the last 18 months, under the eye of the PuWG, BNFL has embarked on a programme of work to examine the relative merits of the available options.

3. Options for disposition

There are three basic options for managing the UK Pu stockpile :

- continued storage as a zero value asset against future use
- immobilisation as waste for long-term and/or indefinite storage then disposal
- recycle as MOX fuel in reactors followed by spent fuel management

Within these main categories there are several sub-options. These have all been considered in detail against a set of appropriate criteria (see below).

In addition, BNFL believes that there is much potential in pursuing the inert matrix fuel route. This option involves the manufacture of fuel by incorporating the Pu in an inert (non-uranic) matrix such that the energy of the Pu can be utilised in reactor without creating more Pu. In addition, with careful selection of the inert matrix material, the spent fuel may be in a form as robust as any immobilised product for long term storage, with the added advantage of increased proliferation resistance (due to the degradation of the plutonium isotopics during irradiation). Some may also see the inherent radiation barrier as a possible security benefit.

4. Criteria for assessing the options

All options have been assessed for their suitability to assist in the management of the UK's Pu stocks against the following 2 key criteria :

- technical feasibility
- safety and hazard potential

Specific assessment criteria have also been defined as being particularly pertinent to each option and these have been used in the assessment process to assist in reaching conclusions. These are summarised for both the immobilisation and recycle options in Appendix 2.

4.1 Strategic Action Planning

In order to assist in the prioritisation of BNFL's assessments of the various options, the PuWG has made use of the Strategic Action Planning (SAP) process. This process has been successfully employed by the Spent Fuel Management Options Working Group and it was used by the PuWG to focus on the assumptions and uncertainties that would be associated with the pursuit of each of the Pu management options. These assumptions and uncertainties then helped define the investigations which need to be undertaken in order to establish the feasibility and relative merit of the options.

A number of headings under which the various assumptions and uncertainties could be considered in a consistent way were defined for the immobilisation and recycle options. These headings were as follows :

Reactor recycle options	**Immobilisation options**
Interim PuO_2 storage	Interim PuO_2 storage
Manufacturing fuel	Manufacture
Reactor operations	-
Waste management	Waste management
Transport	Transport
Policy	Policy
Regulation	Regulation
Societal issues	Societal issues
Costs and funding	Costs and funding

Having developed the assumptions and uncertainties under each of these headings, these were used to define activities which should be pursued now, or which could be deferred, in order to help resolve the uncertainties and hence assist in making decisions about the various options. Initial feedback from this process was provided to BNFL and used to prioritise work programmes – the process has since continued to be developed in parallel with the BNFL assessment studies.

5. Option 1 : Storage

Plutonium stocks at Sellafield are held in the form of plutonium dioxide powder. The stores are built specifically for the purpose and provide a number of physical, procedural and security barriers to prevent unauthorised access to the material.The design of the stores takes into account a number of potential hazards associated with the handling and storage of plutonium in large quantities, including criticality, radiotoxicity, heat generation, deterioration of packaging and in-growth of americium-241. The stores are subject to international safeguards inspection under the auspices of the IAEA and Euratom.

The essential advantage of continuing to store Pu is that it is an established method (safe, secure and within international safeguards) which allows time for the many uncertainties surrounding the other two principal options to be clarified. While current storage arrangements are satisfactory for at least the next 25 years, the storage option can only be viewed as an interim measure. The PuWG identified two drivers for change in this respect. Firstly, the storage of PuO_2 powder cannot be considered to be 'passively safe' (i.e. requirements for maintenance, monitoring or other human intervention are minimised) implying that long-term, or indefinite, storage cannot be viewed as an appropriate option – current storage facilities are all 'actively managed'. Secondly, increasing international pressure to reduce stockpiles of separated Pu could dictate the need for change.

Nevertheless, it is essential that all material continues to be kept under stringent security arrangements and that all Pu is subject to Euratom and IAEA safeguards and verification arrangements. The existing arrangements were confirmed to be robust in 2000 by the Security and Safeguards Sub-Group of the PuWG and also during a previous review by the Royal Society. Also, given the UK's status as a Nuclear Weapons State, the Pu is not considered to be a domestic proliferation threat.

The implications of pursuing this route, on the basis of current experience, are well understood and can be summarised as follows :

Pros :
- established method – safely, securely and within international safeguards
- does not commit the UK to a course of action before due consultation and consideration
- preserves the asset value of PuO_2
- avoids significant immediate investment
- allows time for technologies to develop (either for recycle or immobilisation)
- allows time for disposal specifications to be set
- allows time for reactor economics to become clearer

Cons :
- stakeholder regards this option as 'deferring the decision'
- leaves the issue to future generations
- stakeholder regards storage as a proliferation issue

To pursue this option beyond existing and planned storage facilities would, as a minimum, require sooner or later expensive repackaging, additional stores to be constructed and safety concerns to be addressed to the satisfaction of the regulators.

5.1 Summary of existing storage facilities on Sellafield Site

The existing product stores at Sellafield are actively managed facilities (e.g. they require powered ventilation systems) and over the medium term, i.e. in many decades time, the currently stored materials could require repackaging and the stores themselves may need to be replaced. However the current Magnox plutonium package and store designs have been successfully used since the 1970’s with no evidence of any life-limiting failure mechanisms being found during destructive and non-destructive examinations. Such studies are continuing [5]. New above ground stores could provide a long-term storage route for suitably-packaged plutonium and other radioactive materials.

The following Special Nuclear Material (SNM) storage facilities currently exist on the Sellafield site :

- THORP Product Store
- Recent Magnox Store
- First Current Generation Magnox Store
- Early Magnox Stores

In addition, plans to construct a new store (Sellafield Product and Residue Store) are underway. This store is designed to be able to accept both THORP and Magnox designed packages and will therefore be flexible in being able to accommodate any historical or future material as required. In planning and designing the new store, care has been taken not to foreclose any of the disposition options. The store is seen as another step along the route to a longer term policy of recycle, immobilisation or a combination of both.

Each of these stores is summarised below. Note that, in this context, 'long-term' is taken to mean over 20 years and 'medium-term' is taken to mean between 5 and 20 years.

THORP Product Store
Commissioned: 1992
Purpose/plans: long-term storage of PuO_2

Recent Magnox Store
Commissioned: late 1990's
Purpose/plans: long-term storage of PuO_2

First Current Generation Magnox store
Commissioned: mid 1970's
Purpose/Plans: long-term storage of PuO_2

Early Magnox Stores
Commissioned: 1960's
Purpose/plans: medium-term storage of PuO_2

Sellafield Product and Residue Store
Planned:
Purpose/plans: long-term storage of PuO_2 plus historic residues.

Plutonium dioxide, PuO_2, produced by reprocessing spent Magnox fuel is packaged in non-PVC bags in aluminium inner cans, historically containing about 5.5kg of plutonium, but more recently in excess of 7kg. Both the product store and the cans are expected to have an operating lifetime of at least a further 50 years. The original PVC packaging used for PuO_2 was found to suffer from radiation-induced deterioration. Non-PVC packaging is now used and a project is underway to provide additional facilities to re-pack those early stocks still in PVC, in line with regulatory requirements.

The capacity of the recent Magnox product store, which has recently been extended to 80 tonnes of plutonium, should be adequate to contain all the arisings of UK Magnox plutonium, based on the current closure plans for Magnox power stations. BNFL's recent increase in the packing density in the storage cans leads to an increase in the capacity of the store. Active commissioning of an extension to this store is expected in the second half of 2002. Any decision by BNFL to extend the store further would not be required until about 2006, by which time the final arisings figure and the full capacity of the store will be known more accurately.

The THORP Product Store is used to store plutonium dioxide from THORP in steel packages, each containing about 7.5kg of plutonium. The product store has been operating since 1994 and again, the individual packages and the product store are expected to have an operating lifetime of at least 50 years. The store has a capacity of about 45 tonnes plutonium.

The total potential arisings of plutonium from reprocessing of UK fuel in THORP are about 25 tonnes from AGRs and (should BE ultimately choose this option) about 6 tonnes from the Sizewell B PWR; i.e. the total UK arisings alone are within the total capacity of the existing THORP product store.

5.2 Characterisation of current stocks

Of the stocks anticipated in 2010, approximately 75% would be derived from Magnox fuel. Of this, approximately 25% would be immediately suitable for fabrication as MOX fuel, approximately 30% would require sampling to verify chemical composition, 40% would require blending and sampling and approximately 5% may require chemical pre-treatment as a result of the chlorine contamination induced by early storage in PVC packages (chlorine in the fuel would have implications for clad corrosion in reactor and as such is tightly controlled by specification limits).

The UK plutonium resulting from the reprocessing of AGR spent fuel, which belongs to BE, is stored in the THORP Product Store. All of this material is suitable for fabrication as MOX fuel, should BE choose to do so.

5.3 Summary of storage option key points

- continued storage is an acceptably safe, secure and safeguarded option for the near future
- storage cannot not be viewed as a viable long-term solution (beyond around 25 years)
- existing and planned stores at Sellafield do not preclude any Pu management option (immobilisation or recycle) from being pursued in the future

6. Option 2 : Immobilisation

Immobilisation results in the conversion of plutonium to a stable waste form suitable for long-term storage and disposal.

The project to assess the various immobilisation options has been divided into a number of phases and associated tasks. In phase 1 the first task was to identify possible options, through literature search and networking, which are currently under consideration world-wide.

6.1 Previous Work

It should be noted that in 1998/9 BNFL undertook a brief evaluation of the various options being considered internationally for immobilising plutonium, noting those topics which required further research before final disposition routes could be chosen. The study (see Appendix 1) concluded that glass and ceramic wasteforms show the greatest potential for bulk plutonium immobilisation and have undergone the most research; both, however, have their advantages and disadvantages. It was suggested then that the final choice of wasteform may ultimately depend on the exact remit given for plutonium immobilisation and the criteria chosen for disposition and disposal. Other wasteforms, such as sinter glasses and electrometallics etc, are technically viable but are generally less well developed and are not perceived to show any particular advantages over glass and ceramics, either in terms of processing and/or final wasteform performance.

It was recommended at that time that further work was required to determine which option would actually be viable on an industrial scale, as there are many outstanding issues that need to be resolved for both the vitrification and the ceramics options. However, whichever option is pursued the following topics need to be addressed.

- Definition of process feeds and flowsheets
- Optimisation of process operational envelopes
- Definition of methods of criticality control and shielding requirements
- Qualification of the wasteform
- Resolution of long term environmental and disposal issues

The study group also recommended that

- BNFL keep a watching brief on world-wide development in the field of plutonium immobilisation
- BNFL should keep all vitrification and ceramics options open until some of the technological uncertainties have been resolved

The American can-in-canister concept was not pursued as part of this investigation because it was deemed unlikely that large quantities of HAL/VHLW would be available for backfilling the canisters on the timescales required for a 'late immobilisation' strategy.

6.2 Current Work

The options examined as part of that study were subsequently revisited along with those identified since that review. The options identified by the Pu Working group in their interim report [1] were also incorporated where appropriate in this current project.

Ten immobilisation options were identified. These are listed in Table 6.1. Work progressed on 6 of these options (Nos. 1, 2, 4, 5, 7 and 10) in the following areas:

- Outline Process description
- Technical assessment
- A 'trial' Best Practicable Environmental Option (BPEO) type exercise on the 6 options
- Development Requirements exercise
- Literature survey
- Risk Review
- Review of work on-going in the US

Findings and conclusions under each of these headings are outlined below (sections 6.4-6.10).

Broad orders of cost only were used in the 'trial' BPEO exercise. These have been based on BNFL's own experience of plant/facility construction and operating costs.

It should be noted that the SMP low spec MOX option, raised by some NGOs as an alternative to SMP receiving Government approval to commence commercial MOX operations, has not been pursued further by BNFL. Since approval was given for SMP (December 2001), plutonium has been brought into the plant and a programme of full MOX fuel qualification and manufacture for customers is underway. 'Dual operation', that is processing both low spec and normal high spec MOX through adjacent manufacturing lines, has also been rejected as impractical for several reasons, principal amongst them being the need to prevent cross-contamination of the normal high spec product for customer acceptability, operational, quality and regulatory reasons. In the longer term, when SMP has reached the end of its operating lifetime, it will undoubtedly require considerable refurbishment and thus negate many of the potential economic benefits claimed for pursuing a low spec MOX option.

In general, notwithstanding the availability or otherwise of SMP as a means of producing low spec MOX, this option is not favoured by BNFL for plutonium immobilisation. This is because the final form for any immobilised plutonium would be expected to have intrinsic security qualities that exceed those for the plutonium oxide feed or the preferred alternative, MOX fuel. Manufacturing low spec MOX, with its associated costs, would not achieve this. It may be preferable, therefore, to examine other immobilised forms that result in the plutonium being highly dispersed in its matrix, diluted, and in a final form that makes the plutonium extremely difficult to recover and difficult to move without specialist equipment.

Table 6.1 - Immobilisation Options

No	Option	Process	Initial Assessment
1	**Ceramic – New build**	PuO_2 converted to ceramic pucks (95 mm diameter, 16 mm thick) using a purpose designed matrix material. Pucks loaded into Pu cans. New purpose-built facility required. Cans are held in interim store pending ultimate disposal.	Worth pursuing further
2	**Ceramic – SMP Mod**	SMP modified at the end of its MOX fuel producing lifetime to produce ceramic pucks (95 mm diameter, 16 mm thick) using PuO_2 and a purpose designed matrix material as in 1 above. Pucks loaded into Pu cans. Cans are held in interim store pending ultimate disposal.	Worth pursuing further
3	**Low Spec MOX - SMP mod**	SMP converted at the end of its MOX fuel producing lifetime to produce low spec MOX pellets which would be loaded into sealed rods within the plant. These rods would then be transferred to a suitable facility for interim storage pending ultimate disposal.	For later assessment* **PuWG asked for this option to be included along with the initial options selected - April 2001**
4	**Vitrification - New Build**	New vitrification facility. PuO_2 powder is vitrified in suitable glass. Poured into Pu can for interim storage pending ultimate disposal.	Worth pursuing further
5	**Ceramic + VHLW barrier- New build**	PuO_2 converted to ceramic pucks (95 mm diameter, 16 mm thick) using purpose designed matrix material and loaded into Pu cans. Cans are loaded into VPS style canisters and surrounded by VHLW. Canisters are stored in VPS style facility pending ultimate disposal.	Worth pursuing further **PuWG asked that a variant of this option using the existing Vit Plant be pursued - April 2001**
6	**Ceramic + barrier- New build**	PuO_2 mixed with some form of HLW, formed into ceramic pucks using a purpose designed matrix material. Pucks of the same dimensions as in 1 above. Pucks loaded into Pu cans. Cans loaded into VPS style canisters for interim storage pending ultimate disposal.	Considerable engineering difficulties in mixing α and β plant. Product not perceived to bring benefit over can-in-canister. No further work at this time.

Table 6.1 - Immobilisation Options (Continued)

No	Option	Process	Initial Assessment
7	**Ceramic + VHLW barrier - SMP Mod**	SMP modified at the end of its MOX fuel producing lifetime to produce ceramic pucks (95 mm diameter, 16 mm thick) using PuO_2 and a purpose designed matrix material as in 1 above. Pucks loaded into Pu cans. Cans then loaded into VPS style canisters and surrounded by VHLW. Canisters are stored in VPS style facility pending ultimate disposal.	Worth pursuing further
8	**Low Spec MOX + VHLW barrier - SMP Mod**	As option 7 but instead of ceramic pucks, low spec MOX pellets would be produced and loaded into Pu cans. Cans then loaded into VPS style canisters and surrounded by VHLW. Canisters are stored in VPS style facility pending ultimate disposal.	Because of similarity to 7, defer further assessment until later
9	**Low Spec MOX + Spent Fuel barrier - SMP Mod**	As option 3 but the sealed rods would then be transferred to a suitable facility for loading into appropriate spent fuel assemblies. Spent fuel rods would be removed and the low spec MOX rods inserted such that the remaining irradiated rods would act as a radiation barrier.	This option has not been pursued further since it raised a number of questions e.g. dose uptake wrt spent fuel handling required, what happens to the irradiated rods removed from the assemblies, etc. **Pu WG asked that the alternative option of building complete assemblies with low spec. MOX fuel rod and then storing these with spent fuel in storage ponds on the site be assessed.** **April 2001**
10	**Vitrification + Barrier - New Build**	New vitrification facility. PuO_2 is vitrified in glass. Poured into Pu can. Cans are loaded into VPS style canisters and surrounded by VHLW. Canisters are stored in VPS style facility pending ultimate disposal.	Worth pursuing further

6.3 Key Assumptions

For the purposes of the preliminary investigation a number of key assumptions were made. These are listed below:

1. The facility will be operational by 2015
2. The overall utilisation of the facility will be 200 days/ annum
3. It will treat in 10 years, the contents of approx.15,000 standard Magnox can packages
4. SMP modifications would occur post completion of the SMP order book.
5. Vitrification
   - An incorporation rate of 7.5wt% PuO_2 [6]
   - The immobilised waste will be packaged into containers of Pu product can type dimensions
6. Ceramics
   - The finished sintered puck size will be 95mm diam x 16mm thick.
   - A PuO_2 loading of 10 wt% is assumed [7].
   - The pucks will be loaded into THORP Pu can style packages and stored in facilities of similar design to the TPS product store.
7. With radiolytic barrier options, the outer package will be of VPS container type dimensions
8. Interim stores are assumed to be operational for at least 30 years.
9. No assumptions have been made re. ultimate disposal route and no costs included.

Assessments of options 1, 2, 4, 5, 7 and 10 against the various headings are considered below:

6.4 Process Description

Outline process flow sheets were prepared for each of the options.

6.5 Technical Assessment

<u>Vitrification or Ceramic</u>

For the immobilisation of plutonium the project considered glass and ceramic as possible matrices.

It was concluded that for the case of high plutonium content, whilst vitrification of HLW is an established technology, the reduced leachability of ceramic make this the preferred technology. The increased waste loadings in ceramic over glass (although glass has an increased tolerance to feedstock impurities) also make ceramic the preferred choice. In addition criticality control is expected to be easier for a ceramic. It should be noted that immobilisation in a ceramic was also the preferred technology for the US disposition programme [7,8]

6.6 'Trial' BPEO Exercise

As part of the project, a 'trial' high level scoping ‘BPEO’ type exercise was undertaken as a means of comparing the environmental impacts of one option versus another as an aid to decision making. This exercise was carried out as a precursor to a more detailed exercise which was proposed for later in the project when comparisons with all plutonium management options could be made.

An option which is deemed the Best Practicable Environmental Option (BPEO) is “the outcome of a systematic and decision-making procedure which emphasises the protection and conservation of the environment across land, air and water. The BPEO procedure establishes, for a given set of objectives, the option that provides the most benefit or least damage to the environment as a whole, at acceptable cost, in the long term as well as in the short term” [9].

The results from this 'trial' BPEO are summarised below.

6.6.1 Methodology

An outline decision analysis model was drafted. Internal experts were then identified against a number of the criteria, with, in most cases, a prior knowledge of the options. The intention was to utilise the experts to rank and rate the options against their area of expertise, through 1-1 sessions, rather than requesting input against all attributes/criteria, or convening a decision conference/workshop. The criteria are given in Appendix 2(i).

A matrix was derived with which to commence the 1-1 sessions. The purpose of the matrix was to allow direct comparison of all leading options against a set of predetermined assessment criteria. The top-level criteria were Cost, Stakeholder Preference, Technical Viability and EH&S.

The output from the matrix was fed into a computer model to identify the Best Practicable Environmental Option (BPEO) i.e. that option which performs ‘best’ overall against all of the assessment criteria.

6.6.2 Decision Analysis

This section summarises the main aspects associated with the incorporation of the data obtained through the 1-1s into the Multi-Attribute Decision Analysis Model.

Whilst scoping the BPEO study a number of issues were identified which included the application of weighting, and the inclusion of an attribute representing stakeholder groups within the decision model.

There are numerous reasons for uncertainties in the application of weightings within the decision analysis models. They are primarily related to their potential use to skew a decision in favour of the proposer. The reality is that through not weighting a decision model, there is actually an artificial bias placed upon the least important attributes/criteria. As such, there is not an unweighted model, but an equally weighted-model, which does not represent reality, or cognitive structures. This study has therefore undertaken the decision analysis with the intention of presenting the results in both formats – weighted and unweighted, as shown below.

Similarly, the inclusion of assessing likely stakeholder preference within internal optioneering studies has presented interesting challenges. There are many methods and reasons for including the assessment of stakeholder preference within optioneering. The reasons for including the stakeholders are generally intended to reflect and incorporate the preference of disparate groups, which may include the regulators, the local public, non-governmental organisations, international concerns, etc. The issues addressed through inclusion of these bodies are, in some cases, fundamental to the success or otherwise of any given option. For example, an option could score very highly on the technical, financial and EH&S attributes within a study, but be contrary to the wishes of international parties, the UK government and the regulators.

Whilst there is strong reasoning to support the inclusion of the stakeholder attribute and associated criteria, there is a question over the use of internal ‘proxy’ representation for these external parties. There are methods for more formal inclusion of external opinion, which includes education and information provision; information and feedback; involvement and consultation; through to extended involvement, e.g. the stakeholder dialogue. Some of these approaches are already in use within BNFL. It is recognised that the value, and need for more inclusive decision making, changes throughout the lifetime of a project. It is therefore considered that an internal process for ‘proxy’ representation is appropriate for the current phase of work. As such, the decision analysis work has been prepared in a format which represents the decision models both with and without the stakeholder attribute.

Commercially available Decision Analysis software (HIVIEW) was utilised to support this study.

The four decision analysis models used therefore are:

- with Stakeholder attribute :
  - Unweighted
  - Weighted
- without Stakeholder attribute :
  - Unweighted
  - Weighted

6.6.3 Results from the 'Trial' BPEO study

i. Unweighted model with Stakeholder attribute

The overall performance indicates the preference for the Ceramic New Build and Ceramic Modified SMP options. Also the options appear to perform consistently well against all attributes, whilst the Vitrification No Barrier option ranks lower primarily through poorer performance against the Technical and Stakeholder attributes. In comparison, the remaining options are observed to perform relatively poorly against all attributes.

ii. Weighted model with Stakeholder attribute

The weighting in this instance has the effect of depressing the performance of those options previously observed to be performing poorly within the unweighted model.

iii. Unweighted model without Stakeholder attribute

In the unweighted, no stakeholder model, the most significant change is to increase the relative preference for the Vit No Barrier option and to slightly enhance the overall preference for the Ceramic New Build option.

iv. Weighted model without Stakeholder attribute

Removal of the stakeholder attribute has again, as with the unweighted model, increased the relative preference for the vitrification new build without barrier option and extended the relative preference of the Ceramic New Build option. However, the weighting has also depressed the relative overall performance of the ceramic new build with barrier option and the ceramic SMP modification with barrier option, although it should be observed that the overall option preference profile, and lead options remain the same throughout.

6.6.4 'Trial' BPEO Conclusions

It is concluded from the 'Trial' BPEO study that, despite some minor variations in relative scorings, the best scoring options were the Ceramic New Build and the Ceramic Sellafield Mox Plant Modification regardless of extreme changes in weightings.

6.7 Development requirements

The processes under consideration fall broadly into two categories: options involving ceramic technology and options involving vitrification technology. The development tasks are considered as follows:

1. General development common to either technology
2. Development specific to the ceramic based options
3. Development specific to the vitrification based options

6.7.1 General Development Work - Operational Development

Operability research will be required to support the design of the process and ensure that an optimised process is achieved. This will include:

- Identification of an optimum transport package and transport vehicle for the transfer of material from current storage to the treatment facility
- Optimisation of the interim store and the package to be stored.

6.7.2 General development - Process Development

The process development will include issues such as:

- Provision of rework facilities
- Decontamination of empty cans to allow disposal as LLW
- Determining the potential implications of receiving contaminated feedstock
- Validation of the product through process control

6.7.3 Development specific to ceramic based options

Development requirements for the ceramic-based options will include:

- A literature review to confirm the choice of waste form, choice of process, and highlight the additional work required out on the feedstock prior to designing the plant.
- Definition of the criteria against which the product is to be tested in order to determine whether the wasteform is suitable for long term storage.
- Production of inactive product samples including a Pu surrogate to demonstrate the degree of milling and mixing required, the required puck size, optimisation of the cold pressing and sintering parameters.
- Establishing the preferred waste loading
- Production of an active sample to test for radiation damage and long term durability.
- Full scale active trials to demonstrate operation envelope for each of the process stages.

6.7.4 Development specific to vitrification based options

Development requirements for the vitrification-based options will include:

- A literature review to confirm the choice of waste form, choice of process, and highlight the additional work required out on the feedstock prior to designing the plant.
- Establishing selection criteria for the choice of glass
- Establishing and undertaking a test programme to select the optimum glass for the immobilisation of Pu
- Carrying out full characterisation of both active and inactive glass samples
- Consideration of the potential for the vitrification of the whole package
- Definitions of the operating envelope, methods of melter control, establish throughput rates, characterisation of the feed system and material rework.
- Melter development

6.7.5 Collaboration and University Links

The literature survey (See Section 6.8 below) and contacts with other researchers have identified outside organisations with the capability of producing ceramic wasteforms for the immobilisation of plutonium. The basic technology has been developed by ANSTO in Australia and was further exploited by a Lawrence Livermore led team in the USA for the immobilisation of excess weapons plutonium. This work has led to an identified formulation and process which is currently undergoing testing. Information on the results of these tests is awaited.

Recognising the importance of immobilisation as an option for waste and actininde disposal, BNFL has embarked upon a collaborative Research Programme with the University of Cambridge. This is a corporately-funded programme which began in November 2001 and will extend over a period of 5 years. Its remit is to research generically the use of synthetic mineral analogues as host phases for actinides and plutonium. As such, this work is not targetting any particular waste stream or immobilisation option but will ensure that the underpinning science is in place to support any immobilised wasteform of choice. The programme includes three main activities - understanding the fundamentals of radiation damage in ceramics, examining the durability of potential ceramic waste forms and examination of active samples.

The first activity covers the development of a fundamental & quantitative understanding of the damage caused to crystalline structures by accumulated radioactive decay events - experimental and computational. This is specifically aimed at determining the amount of damage caused by the recoil nuclei of alpha-emitting, heavy nuclides in different host materials. The work is designed to determine the nature of the accumulation and aggregation of damaged regions in the host materials.

The second activity, examining the durability of potential ceramic waste forms, is aimed at understanding the influence of percolating vs non-percolating damaged regions with respect to leaching, gaining knowledge on the effect of grain size and connectivity of most leached grains through accelerated leaching experiments and determining the influence of leachate trace element composition on leaching of waste forms.

The third activity, the examination of active samples, is aimed at developing limits for loading levels in host phases based on knowledge of the physics and chemistry of damage process, and, more specifically, evaluating neutron activation vs direct actinide substitution as production methods for active samples.

Work is also being carried out at the University of Sheffield's Immobilisation Science Laboratory (ISL), primarily extending research into cementation and vitrification with a view to underpinning the immobilisation technologies currently used within the Company. BNFL is committed to a financial input of £2M over 5 years supporting 5 permanent academic posts and up to 40 researchers. Examples of some of the work taking place or planned include examination of the science behind the production of calcine suitable for making good glass, prediction of the behaviour of waste-loaded glass under repository conditions and the examination of the variation of a range of chemical and physical properties of blended cements over time.

6.8 Literature Survey

A literature review was carried out in 1998 (See Appendix 1). Amongst the conclusions were:

<u>Glass</u>

- Borosilicate is accepted as the international standard for HLW immobilisation.
- Maximum waste loadings achievable in glass are likely to be in the range 3%-10%
- Glass compositions exist allowing incorporation of plutonium at <5% in standard borosilicate compositions melting at 1100C and also 5%-10% in lanthanide borosilicate compositions at >1400C.
- Glass is likely to be more flexible than ceramic in terms of impurity acceptance

<u>Ceramic</u>

- Ceramic wasteform technology developed by ANSTO has yet to be used "actively"
- High plutonium loadings could be achieved with minimal volume and good durability
- A MOX production facility could be converted into a ceramic immobilisation facility
- Criticality control is expected to be easier in the preparation of ceramic than glass

Since the time of this review, the US DoE [7] settled upon the ceramic can-in-can option for ex-weapons plutonium immobilisation (see section 6.10 for more information on the US position). Work continued in this area but was curtailed in the vitrification area where emphasis was put on the immobilisation of other actinides. As a consequence, a further literature survey review has been carried out (See Appendix 3 for list of references). A summary of that review indicates:

- A titanate ceramic pyrochlore formulation has been arrived at with a defined processing cycle
- Good if variable leach rates for such pyrochlore-based waste forms have been noted. This is largely due to the fact that a standard leaching test for this material has not yet been established. Note that worst leach rates are circa 1 atomic layer per day with better leach rates from tests more closely simulating repository conditions.
- The role of impurities has been studied and effects vary according to species, with currently conflicting evidence on leach rates. Note that in no case does the leach rate become unacceptably high.
- Natural analogues are being studied in order to confirm long term stability of the synthetic pyrochlore-type wasteforms. Chemical analyses to date indicate that elements such as thorium and uranium have been retained over geological time periods in natural zirconolites thus underpinning the suitability of the pyrochlore class of materials as nuclear waste forms.

The review of external work will continue and will also include any work being carried out on can-in-can process development, as and when data becomes available.

6.9 Risk Review

Risks associated with all the Pu immobilisation options have been reviewed. This was a multi-discipline review covering all types of risk. The scope of the review covered:

1. Risk identification,
2. The evaluation of the probability of the risk, its cause and effect
3. The definition of a risk management strategy.

The initial risk review identified over 40 top-level risks. An analysis of the risk register showed two main themes. These were:

1. The uncertainty in the project definition (e.g. feed scope, product. specification).
2. The immaturity of the design and development work.

The risk register at this point in time has insufficient data to enable a clear distinction to be made between the Pu immobilisation options. However, one distinction that can be inferred from the data is that the “barrier” options provided the highest risks.

6.10 US Position

The US DOE is pursuing an approach to Pu disposition that would make surplus weapons-usable plutonium inaccessible and unattractive for weapons use. The DOE's disposition strategy initially allowed for both the immobilisation of some (and potentially all) of the surplus plutonium and use of some of the surplus plutonium as MOX fuel in existing domestic commercial reactors.

In this context, the US investigated a number of options for the immobilisation of surplus plutonium [7] and their preferred choice was the can-in-canister technology [8].

The preferred immobilisation option consisted of three primary stages. The first step converted non-pit surplus plutonium into plutonium dioxide and conditioned other impure plutonium oxides. Next, the plutonium was to be immobilised in a ceramic matrix and finally the cans containing the ceramic matrix were to be encased in vitrified high level waste, which would form a radiation barrier to possible theft or diversion [10]. The DOE planned to have the new immobilisation facility operational by 2005. The facility was designed to operate for about ten years and would have immobilised approximately 18 metric tons of plutonium.

More recently, the US DoE has dropped the immobilisation option from its weapons disposition programme in favour of MOX utilisation in reactors.

6.11 Cost Estimation

Work in this area has only been of a very preliminary nature while details of the process flowsheets are more clearly defined. At the moment cost ranges have been developed in terms of the degree of complexity of the plants required for each option and past operational experience on the Sellafield site of similar plants. Lifetime costs assume a 10 -15 year process plant life and a 30 - 50 year interim storage period. Decommissioning, dismantling and demolition costs can only be assessed in the light of past experience. Allowances for risk and associated infrastructure have yet to be assessed.

For the 'trial' BPEO analysis relative costs of options were required. The order used was

SMP Mod (With or Without Barrier) <

Ceramic New Build (With or Without Barrier) <

Vitrification New Build (With or without Barrier)

6.12 Security and safeguards issues

The immobilisation route, whether low spec MOX or some form of ceramic puck production, will require a degree of plutonium processing in the un-irradiated state. Full processing details are not established at this time but the differences between the MOX and immobilisation routes for UK owned civil plutonium are unlikely to be significant in safeguards and security terms. Both will require the processing plants to have Category 1[1] security protection and both will need comprehensive safeguards arrangements involving facility design information, accountancy and control, containment and surveillance measures and timely verification.

The issues for the facility that would need to be constructed in order to combine the un-irradiated low-spec MOX or immobilised plutonium pucks with highly radioactive material to create a radiation barrier have similarities with those for a MOX-fuelled reactor. Just as nuclear reactor fuel ponds hold fresh MOX fuel prior to loading, the immobilisation plant will need to have a store to temporarily house plutonium pucks etc prior to the addition of a radioactive barrier. It will therefore need Category 1 security protection and full safeguards. Subsequently, as the pucks etc are processed and a highly radioactive barrier is added, the security and safeguards regimes can be reduced in line with existing international standards.

The final immobilised product will need significant security protection although this will depend on a number of technical features such as the radiation field and plutonium content of the product. Continued management oversight will be required during interim storage, pending final decisions on long-term management. The immobilised product has a protective radiation field that decays with time, rendering the plutonium more accessible (in theory at least), although expensive engineering facilities would be required to extract the plutonium. Although the risk of undeclared diversion is minimal in a UK context, it cannot be ruled out completely.

6.12.1 Effects of adding a radiation barrier on security and safeguards

The system of International Safeguards has a central goal of verifying that civil material is not diverted from peaceful end-use commitments and it uses methods of re-verification to achieve this goal. This requires Inspectors to have access to the nuclear materials to re-measure stocks and flows and to protect their continuity of knowledge through containment and surveillance. In the case of the THORP store for example, Euratom (and the IAEA) reserve the legal right to re-verify (re-measure) every can of plutonium in store if they, at any time, believed that continuity of knowledge had been compromised. Under normal arrangements, the Inspectors rely on a complex set of sealing devices, coupled to their CCTV cameras in the store to provide the necessary assurances, as well as 100% verification of all plutonium entering and leaving the store. They also randomly select a number of cans for re-measurement at the annual inventory.

Proposals to add a radiation barrier to the stored plutonium would not make re-verification easy and considerable thought would have to given to how this could be achieved. Similarly, the standard technique used to measure the plutonium content of plutonium oxide is by neutron coincidence counting and gamma spectroscopy. These methods have become highly refined and routine over many years and result in high precision measurements. The intentional inclusion of neutron poisons in immobilised plutonium (to control long-term criticality in a repository) would generate significant measurement difficulties that would

[1] In determining the level of physical protection to be implemented for nuclear materials in use, storage or transport, account is taken of the possibility that the unauthorised removal of the material could lead to the construction of a nuclear explosive device. Categorisation of material by type, isotopic composition, physical and chemical form, degree of dilution, radiation level and quantity determines the level of physical protection required. Category 1 is the highest level of security.

require consultation with the Safeguards Inspectorates to see if revised techniques could be developed. This would not be a trivial task.

From a security perspective, all nuclear materials can be successfully guarded but the costs of guarding direct-use materials are usually higher than other nuclear materials such as spent fuel. In theory, converting plutonium into forms with a radiation barrier would reduce the costs of security, but in practice the security needs for a site such as Sellafield are largely determined by overall site requirements and the presence or absence of any one material type or facility is largely irrelevant.

The security threats that must be defended against include sabotage and theft and the material form and storage arrangements have a bearing on the relative risks and that is why security arrangements are tailored to suit the risk. In this respect, the presence of a radiation barrier around immobilised plutonium does not seem to be of immediate or obvious benefit. On the one hand it might prevent or make more difficult the theft of the material and gaining access to it for purposes of sabotage (clearly this depends markedly on the scenario and if the storage container is shielded). Conversely, the successful sabotage (i.e. dispersal) of highly radioactive waste in addition to plutonium is likely to cause additional difficulties for subsequent decontamination.

In principle, there could be benefits in, firstly, dispersing the plutonium in a matrix that makes recovery difficult and, secondly, storing the material in heavy containers or robust stores, as long as the safeguards regime is acceptable to International Regulators. "Intrinsic security" would be enhanced because the risk of theft would decrease under some scenarios, the plutonium might be more difficult to separate and the matrix/container/store would provide substantial resistance to ballistic forces, so minimising the risk of dispersal. However, regulations require security measures, including institutional arrangements, to be tailored to the type and form of nuclear material, with the aim of providing comparable security whatever the material. On this basis the only justification for including a radiation barrier for immobilised plutonium would be in the political context of international, bilateral assurances relating to nuclear weapons' disarmament. Indeed, this is the only context in which the Spent Fuel Standard has any meaningful definition.

Nonetheless, given the PuWG's view that an alternative approach to the management of plutonium stocks needs to be developed, there would be merit in examining further if other "intrinsic security" arrangements should apply. These might include but not be limited to; difficulty of separation of plutonium from its matrix, difficulty of extracting plutonium from its storage container and difficulty of moving the storage container.

6.13 Summary of immobilisation option key points

- immobilisation is a likely candidate for a part of the UK stockpile for which technically feasible, but costly, pre-treatment prior to MOX manufacture would be required
- technical and economic uncertainties associated with the relative immaturity of the various immobilisation options mean that immobilisation cannot yet be viewed as an acceptable long-term solution for the rest of the UK stockpile without a significant development programme

- the American can-in-canister concept has not been pursued as part of this investigation because it was deemed unlikely that large quantities of HAL/VHLW would be available for backfilling the canisters on the timescales required for a 'late immobilisation' strategy
- BNFL and the PuWG agree that the ceramic immobilisation option is preferred over the vitrification option and, unless a major breakthrough is made internationally, BNFL does not plan to sanction development work on the direct incorporation of PuO_2 into glass as a method of immobilisation
- BNFL has embarked on significant funding of collaborative programmes with the Universities of Cambridge and Sheffield in order to gain a better understanding of the underpinning technologies for immobilisation techniques

7. Option 3 : Reactor Options

Recycle of UK plutonium as MOX fuel could be achieved via a number of sub-options, including use in existing UK reactors or in future reactors built in the UK. Without subsequent recycle of irradiated MOX fuel, the Pu stockpile would eventually be reduced to zero as it was converted to a spent fuel standard for storage or disposal.

It is worth noting that the utilisation of MOX fuel in a reactor, compared with the use of UO_2 fuel, makes virtually no difference to the overall generating cost of the electricity produced since the fuel cycle component of the overall cost of generation is small.

The initial task of the study was the identification of reactor types currently in operation in the UK and overseas [11], and of those of advanced design which are either under construction or yet to be ordered. A review was also carried out to identify those operating reactors which have already utilised MOX fuel in their cores [12].

7.1 Reactor types

The tables attached summarise the findings. Table 7.1 lists the types of commercial nuclear power stations currently in operation throughout the world and identifies those which have already burned MOX fuel in their cores.

The availability/suitability of UK reactors to burn MOX can be initially assessed in terms of technical feasibility, reactor lifetimes and the owners' own assessment of economic viability. With these criteria in mind, it is the view of BNFL that Magnox reactors, with their current lifetime projections and the technical challenges which would have to be overcome, do not represent a viable option.

The case for burning MOX in the UK's AGR reactors, while less challenging from a technical standpoint than utilisation in Magnox reactors, still presents a number of practical difficulties, some of which have been noted by the Royal Society [13].

The suitability of Sizewell B for burning MOX from a purely technical point of view is relatively easy to assess since Sizewell B is similar in design to reactors which have already been licensed and operated with MOX core loadings. Clearly some modification to the reactor would be required and a new licence sought but in looking to the future, British Energy themselves have carried out an assessment of the requirements and concluded that it would be possible [14].

The Sizewell B PWR could potentially use plutonium at the rate of 0.5 – 0.7 tonnes per year, based on an approximate 30% MOX core fraction. Assuming a 5-year ramp-up period to this level, Sizewell might use about 14 – 20 tonnes of plutonium over its scheduled lifetime (i.e. operating until 2035). Therefore, the UK’s only existing PWR could irradiate (and convert to spent fuel) only about a third of the current stockpile of separated plutonium over its planned lifetime.

Table 7.2 lists the new reactor designs currently under construction or still being developed which could burn MOX fuel. BNFL, with its recent acquisitions, first of Westinghouse and later of ABB nuclear business, now possesses a broad portfolio of reactor designs. These fall into four types:

- Designs which have evolved from current reactor platforms, CPWR, KSNP and KNGR, APWR, BWR90+ and System 80+ (these designs, with the exception of the System 80+, have a range of features developed specifically for a local market. The System 80+ is more suitable for a global market).
- Advanced Passive (AP) ALWR's, such as AP600 and AP1000, are suitable for deployment in the short term in a range of geographic regions.
- Pebble Bed Modular Reactor (PBMR) - a novel reactor concept, which is attracting world-wide interest.
- Generic platforms which are conceptually novel and which are aimed at the longer-term deployment. These still require significant further development and, most likely, a prototype before a commercial station would be built. The most relevant example is the International Reactor Innovative and Secure (IRIS) concept.

Other systems available or being developed in the wider market include Framatome - ANP European Pressurised Reactor (EPR), Framatome-ANP CNP-1000, GE/Toshiba/Hitachi Advanced Boiling Water Reactor (ABWR), AECL CANDU-9 (PHWR) and the Atom-energostroy VVER-1000 (PWR).

Table 7.3 shows an initial assessment of the various reactor options against the key criteria.

7.2 Incentives for burning Pu as MOX in new reactors

The possible role of new reactors in the management of plutonium would be just one factor to be included in the wider considerations about the future of nuclear power in the UK. The Cabinet Office Performance & Innovation Unit (PIU) has considered the policy issues relating to new nuclear power in the UK as part of its current energy policy review. Any decision (by government or industry) that supported the introduction of new reactors in the UK would be made after careful assessment of a wide range of issues, including UK energy requirements, impact on greenhouse emissions, radioactive waste management, public acceptability, regulatory concerns and economics. BNFL's submission to the PIU Energy Policy Review [15] highlighted the incentives for new reactor build in the UK in the areas of :

- <u>safety</u> : the nuclear industry's safety record is impressive
- <u>security of supply</u> : diversity, stability, reliability, availability
- <u>cost effectiveness</u> : costs competitive with other energy sources
- <u>minimal emissions</u> : nuclear has virtually no CO_2, SO_2 or nitrogen oxide emissions

Although both the AP600 and AP1000 reactors are capable of burning MOX fuel, and consequently represent options for helping to reduce the UK stockpile of Pu, more recent assessments have focused on the AP1000. The projected UK stockpile could be consumed by 2 AP1000 stations on full (100%) MOX cores over a 20 year period. This equates to around 1600 tonnes of fresh MOX fuel production i.e. around 80 tonnes of MOX fuel per year for 20 years. It is therefore of comparable throughput to SMP and would be sufficient to deal with projected plutonium arisings.

Other reactor systems such as the PBMR would be feasible alternatives but are less well advanced in terms of design and licensing and would require different fuel manufacturing facilities from SMP.

7.3 Usability of the Pu stockpile in MOX fuel manufacture

Although some of the UK Pu stockpile may require treatment (see Section 5.2) it is expected that the greater part of the plutonium held can be fabricated into MOX fuel. Americium-241 ingrowth is one issue which can affect the usability of the Pu. ^{241}Am forms from the radioactive decay of ^{241}Pu. ^{241}Pu is a fissile isotope whereas ^{241}Am is an absorbing isotope hence the longer the separated Pu is stored before fabrication into MOX fuel and loading in a reactor, the less fissile the MOX fuel will become. Also, since ^{241}Am is a gamma-emitter, the greater will be the potential dose received from the Pu or MOX fuel.

The vast majority of the current UK stockpile of separated plutonium has been generated in Magnox reactors. This has a low ^{241}Pu content and means that ^{241}Am is not a problem and plutonium separated from Magnox spent fuel can be processed through plants such as SMP without difficulty even after being stored for some 60 years after separation.

AGR generated plutonium has a higher ^{241}Pu content than Magnox derived plutonium which has the effect of reducing the allowable storage time before operator dose limits would be exceeded in the processing of MOX fuel. The storage time for AGR derived plutonium is estimated at around 10 to 15 years.

LWR plutonium has a higher ^{241}Pu/^{241}Am content than AGR generated plutonium. This restricts post-reprocessing storage times to a greater degree than for AGR plutonium (to about 5 years). The UK stocks of separated plutonium do not contain any LWR derived plutonium.

In the case of high-americium plutonium, plants such as SMP are more easily able to process the material because of the automated nature of the plant and the positive implications of this automation for worker dose levels.

As regards the issue of reduced Pu fissile content with age, to manufacture MOX fuel which will provide the same lifetime average reactivity in reactor it is simply necessary to increase the amount of Pu added to the MOX fuel mix. The only limitations to this would be :

- any limitations on Pu fissile content in the manufacturing plant

- core design limitations due to the possibility of having a positive void coefficient at elevated Pu levels (generally > 12%). Such a possibility would be avoided at the design stage by assessment against specific design and safety criteria.

7.4 MOX fuel core physics

This section gives a brief description of the implications of MOX fuel on the core design and core physics parameters of thermal reactors.

A plutonium-uranium mixed oxide assembly for a thermal reactor generally looks exactly the same mechanically as a conventional uranium dioxide (UO_2) assembly. But whereas a UO_2 assembly obtains the bulk of its energy from fissions in ^{235}U, a MOX assembly obtains most of its energy from plutonium fissions.

In thermal MOX fuel, only the odd isotopes ^{239}Pu and ^{241}Pu are considered fissile; the even isotopes do not fission to a significant extent and behave as neutron absorbers. ^{240}Pu is different in that neutron captures lead to ^{241}Pu generation so that it can also be considered a fertile nuclide. Both ^{239}Pu and ^{241}Pu have considerably higher fission cross-sections than ^{235}U, but this does not necessarily translate into higher reactivities because they also absorb thermal neutrons more strongly.

The primary effect of the reduced thermal flux in MOX fuel is that thermal neutron absorbers, e.g., control rods, discrete and integral fuel burnable absorbers, xenon, samarium, and soluble boron, have less worth in the MOX spectrum. These absorbers have a more difficult time competing with the MOX fuel for thermal neutrons because of the fuel's large neutron absorption cross-section. This has implications for core design, plant operations, and transient analyses.

7.5 Economics

Studies have been carried out within BNFL on the generating costs for a newly built LWR (both AP600 and AP1000) nuclear plant. During the period while the costing work was in progress, there was a continual evolution of the underlying assumptions and a number of costs were developed. An independent analysis was carried out on the most recent figures and these have been used by BNFL in its submission to the Performance and Innovation Unit (PIU) review of UK Energy Policy and the UK DTI Energy Consultation [15,16].

The results indicate that the generating costs will typically be in the range of 2.2p to 3.0 p/kWh (taking account of costs of capital, operation and maintenance, fuel, spent fuel and waste management and decommissioning). The low end of the these costs assumes a series of identical reactors built in the UK, on existing reactor sites with current infrastructure retained and improved regulatory and planning approval processes. The economics can be further improved by constructing reactors in pairs – the second reactor only costs 80% of the first.

At this level of cost, nuclear generation is comparable to other energy sources for baseload electricity.

7.6 Licensing

Licensing of an AP1000 reactor in the UK has been considered and benchmarked against previous 1993/4 estimates for evolutionary plants. Costs of the order of £200M were suggested.

From BNFL's close involvement with the Sizewell 'B' design and licensing process coupled with a detailed understanding of the differences between MOX and UO_2 fuel designs, many of the aspects of the safety and licensing case which would be impacted by the use of MOX fuel in the UK are well understood. An experiment in the Halden experimental reactor in Norway is already underway, for example, with the express intention of gaining data specific to BNFL's SBR MOX product in anticipation of a future licensing submission in the UK, knowing that the UK has some specific licensing requirements which are not considered in other countries and which would be impacted by the use of MOX fuel.

MOX licensing implications in general need further consideration. Areas such as transport and flask licensing (if the reactor were not sited at Sellafield), dose implications (resulting from the higher actinide inventory in MOX fuel, the different behaviour during fault transients and the whole Probabilistic Safety Assessment arguments), handling and storage need to be addressed. Issues to be considered for the core include whether the initial charge starts with UO_2 fuel and then transitions to a 100% MOX core in subsequent cycles or starts with a 100% MOX core from the outset (no reactor has ever been started up in its first cycle with a 100% MOX core), whether existing operating regimes are appropriate or whether changes are required to keep fuel performance within existing design and safety limits, whether alternative fuel designs (eg the use of annular fuel pellets) are desirable and licensable etc. It is judged that all of these issues will be relatively minor in the context of licensing MOX, given that MOX fuel operates successfully in many plants worldwide.

7.7 Planning and regulatory processes

BNFL, in its submission to the PIU review of UK energy policy [15], called upon the Government to put in place a number of enabling mechanisms to allow new nuclear build to play a legitimate role in the future. These included more equitable climate change abatement mechanisms, a review to enable long-term supply contracts to be put in place at a reasonable price, a policy on financing arrangements for radioactive waste management for new plant and a commitment to encourage the provision of nuclear education, training and research and development.

A key area also highlighted was the need to streamline the regulatory and planning processes associated with the licensing and approval of a nuclear reactor. The current UK planning and licensing process for a new reactor would be expected to take a minimum of 4-5 years. Launch costs prior to start of construction (inclusive of Public Inquiry costs) are estimated to be in excess of £100M.

These costs are compounded by the requirement for further public consultation after construction and prior to commissioning, in order to justify the plant and gain a radioactive discharge authorisation. This has proved to be a prolonged and costly "double jeopardy" process in recent years (eg on BNFL's Sellafield MOX Plant) with no certainty about the outcome. In addition, if the current draft regulatory guidelines which give primacy to the progressive reduction in radioactive discharges are pursued, this would make any proposal for new or replacement nuclear generating capacity in the UK unsustainable. Regulation must be commensurate with the risks and scientifically based.

If replacement nuclear build is to be a realistic prospect in the UK in the future, "fit for purpose" legislation, and more speedy and assured planning/regulatory approvals will be needed. The experience in the USA indicates a possible way forward. The following elements would be a helpful part of a new framework within the UK:

- The adoption of a 'generic approval' process for a reactor design, which should embrace the wider public debate required, thereby avoiding unnecessarily repeated debate at public inquiries as happened at the Sizewell 'B' and Hinkley Point 'C' inquiries. This would be a "once and for all" process analogous to the Design Certification process in the USA.
- Once the reactor design has a "generic approval" the local planning process should focus on site-specific detailed local issues.

Resources to carry out the above processes, in preparation for a future programme of new and replacement nuclear build, are not currently available within the regulatory bodies. The Government was encouraged to reinforce the regulators at the earliest opportunity and to give them an appropriate mandate to support a new nuclear "generic approval" process. Their response and intentions in this area are awaited.

7.8 Security and safeguards issues

For MOX process plants, fuel fabrication involves a variety of automated process stages to manufacture ceramic pellets, fuel pins and assemblies. The initial process stages rely on nuclear materials accountancy and control to give the necessary safeguards assurance but once the MOX is in the form of fuel pins and assemblies, the safeguards regime is considerably simplified and based mainly on item accountancy. Category 1 security measures must be applied throughout the process because the plutonium remains un-irradiated and will be in quantities above the 2kg threshold.

After loading the MOX fuel in reactor, a radiation barrier is produced as a result of normal reactor operations and the radioactive isotopes form an integral part of the fuel. If the reactors are at Sellafield, the transport requirements between the MOX plant and the reactors will be considerably simpler than for off-site movements. Nevertheless, the fuel will need to remain under Category 1 security arrangements until after it is loaded into the reactor. Subsequently, the security can be reduced in line with international recommendations because of the protection afforded by the reactor and the increasing radioactivity of the fuel. Safeguards arrangements for MOX fuel prior to and after loading are applied routinely in Europe.

The final irradiated spent fuel product will need significant security protection although this will depend on a number of technical features such as the radiation field and plutonium content of the spent fuel. Continued management oversight will be required during interim storage, pending final decisions on long-term management. The irradiated fuel has a protective radiation field that decays with time, rendering the plutonium more accessible (in theory at least), although expensive engineering facilities would be required to extract the plutonium. Although the risk of undeclared diversion is minimal in a UK context, it cannot be ruled out completely.

7.9 Summary of reactor recycle option key points

- MOX fuel in reactor provides an intrinsic level of immobilisation and also has the benefit of yielding energy from the Pu with the associated revenue offsetting costs
- MOX fuel represents a mature technology. MOX fuel is already loaded and operating well in several reactors in Europe
- although some of the UK Pu stockpile may require treatment it is expected that the greater part of the plutonium held can be fabricated into MOX fuel
- considering the use of MOX fuel in the current UK operating reactors, Magnox reactors do not represent a viable option, AGRs present a number of practical difficulties and Sizewell 'B' could use about a third of the current stockpile over its lifetime
- of the future systems, the AP600 or AP1000 both represent viable options; 2 AP1000 reactors could consume the current UK stockpile over a period of around 20 years

- generating costs will typically be in the range of 2.2p to 3.0 p/kWh
- the utilisation of MOX fuel in a reactor, compared with the use of UO_2 fuel, makes virtually no difference to the overall generating cost of the electricity produced

Table 7.1 Existing Commercial Power Reactor Types

Reactor Type	**UK**	**Europe**	**North America**	**South America**	**Asia**	**Africa**
Magnox	!					
Advanced Gas Cooled Reactor (AGR)	!					
Pressurised Water Reactor (PWR)	!	!!	!	!	!	!
Boiling Water Reactor (BWR)		!!	!	!	!	
VVER (PWR)		!				
CANDU Reactor (PHWR))			!	!	!	
RBMK		!				

! ! Reactors of this type in these countries are licensed to operate with, and have operated with, significant quantities of MOX fuel.

Table 7.2 - Advanced Reactor Types

Class	Plant	Power Output, Mwe	Approach to Safety	Licensing Status	Operating Units	Units Under Construction Reference
Reference	Sizewell Replica	1200	Active	Yes, UK	1	0
Current Technology Plants	CPWR (3 loop)	1000	Active	Yes, Spain	1	0
	Ohi 3&4 (4 loop)	1200	Active	Yes, Japan	4	0
	Korean Standard Nuclear Plant (KSNP) (2 loop)	1100	Active	Yes, Korea	4	6
Evol, ALWRs	System 80+ (2 loop)	1400	Active	Yes, US	0	0
	KNGR (2 loop)	1400	Active	No	0	0
	APWR (4 loop)	1500	Active	Yes, Japan	0	0
	Fra EPR (4 loop)	1500	Active	Preliminary review, France	0	0
	BWR 90+	1700	Active	Preliminary review, Finland	0	0
	GE ABWR	1400	Active	Yes, US	2	4
Passive ALWRs	AP600 (2 loop)	600	Passive	Yes, US	0	0
	AP1000 (2 loop)	1000	Passive	Preliminary review, US	0	0
Generation IV Reactors	Pebble Bed Modular Reactor (PBMR)	160	Passive	No	0	0
	IRIS	300	Passive	No	0	0

Table 7.3

Items for Consideration with respect to the Use of MOX Fuel in Reactors - An Initial Assessment

CONSIDERATIONS **REACTOR TYPE**	**Technical**	**Utilisation**	**Licensing**	**Manufacture**	**S&S**	**Political**	**UK Government**	**Economics**
MAGNOX	∀	∀	∀	∀	?	∀	!	∀
AGR	!	∀	?	∀	?	∀	∀	∀
Sizewell B	!	∀	!	!	!	!	∀	?
Overseas LWRs	!	?	!	!	!	?	?	?
New Build	!	!	!	!	!	?	?	!

∀ Improbable
? Requires further investigation
! Possible

8. Inert Matrix Fuel (IMF)

Plutonium is inevitably produced from uranium-based fuels as a result of the irradiation of the fertile ^{238}U isotope in the fuel matrix. This forms the utility's growing inventory of plutonium which may either be kept in the spent fuel or separated by reprocessing for storage or reuse. The use of MOX fuel helps to control this growing inventory but, since MOX fuel also contains uranium in the fuel matrix, the burning of plutonium is compensated to some extent by the production of more plutonium from the uranium.

To avoid this inventory build-up, uranium-free fuels known as Inert Matrix Fuels (IMF) are being studied [17,18]. Here, the fissile material is plutonium (only) which becomes exhausted or burnt out during irradiation but which is not compensated for by the further growth of plutonium from uranium.

The most advanced fuel matrix being studied for LWRs is zirconium oxide with the addition of some 5% of fissile plutonium. For reactivity control reasons, adding a burnable poison to the fuel matrix proves to be necessary.

The benefits of IMF compared with standard MOX fuel are :

- fuel does not generate Pu
- fuel assemblies can contain more Pu
- only a 1/8 core loading is required to manage the Pu of a power plant (the so-called 'self-generating mode'), compared with a ~1/3 core loading with standard MOX fuel
- using a 1/3 core loading scheme, excess Pu can be 'consumed'
- fuel elements are designed for direct disposal – IMF solubility in water is believed to be much lower than that of uranium-based fuels
- IMF is proliferation-resistant – the matrix is practically insoluble in acids and the Pu is more effectively depleted
- fuel can be manufactured on a laboratory scale with existing technology
- IMF provides the dual benefits of putting the Pu in an immobilised form while still being able to generate energy and revenue – separate development programmes are not required for both

The disadvantage of IMF is the long development timescales associated with achieving a commercial product. Given the need to complete experimental investigations, pilot loading of test assemblies, post-irradiation examinations etc, it is unlikely that full commercial loading of IMF assemblies could be achieved in anything less than 10-15 years. It is worth noting, however, that IMF can be loaded in current LWRs (such as Sizewell 'B') or future passive LWRs (such as an AP1000) with no reactor modifications.

Since 1995, IMF has been the subject of a series of annual international workshops, examining basic materials and nuclear physics issues, disposition options etc (BNFL has participated in the recent meetings). The main focus of IMF research has been on basic materials properties and perfecting manufacturing techniques on a laboratory scale. Some IMF pellets produced by various fabrication techniques are being tested, for example, in the Halden BWR, and BNFL is maintaining a strong interest in this work. Further plans are under discussion for the selection of the optimal characteristics of this fuel for testing in a commercial LWR.

9. BNFL's international activities in the Pu management area

In carrying out an assessment of the various options mentioned here, BNFL has also drawn on its extensive knowledge of international developments in the management of Pu. BNFL participates in numerous international fora (conferences, meetings, workshops, committees etc). Senior level membership of the IAEA's Standing Advisory Groups on Nuclear Energy and Safeguards Implementation (SAGNE and SAGSI) are just two examples of the degree of involvement the Company has at international level on strategic issues. BNFL also has active members on the IAEA's Technical Working Groups in the areas of Nuclear Fuel Cycle Options and Fuel Performance & Technology, both of which address Pu and MOX fuel issues.

In line with the "Guidelines for the Management of Plutonium" agreed by the group of nine countries which use and produce plutonium in 1997, BNFL has been participating in a wide range of international fora to gauge policy and ensure alignment with internationally agreed best practice in all aspects of Pu management.

BNFL frequently presents papers to international fora including safeguards regulators, such as the IAEA, professional bodies, such as the INMM (Institute of Nuclear Materials Management) and ESARDA (European Safeguards R&D Association) and other nuclear operators.

BNFL also gains much knowledge on international trends on Pu management in direct safeguards support programmes to the IAEA and in support of our customers in Japan. BNFL also has good contacts with the US and Russian state safeguards authorities and takes part in international initiatives involving the management of plutonium.

10. Commentary

There are a number of issues which favour a policy of continued storage e.g. it is an established method, it preserves the asset value of the Pu, it avoids significant investment, it allows time for other technologies to develop and other scenarios to become clearer etc. However, it can only be viewed as an interim measure.

For the immobilisation of Pu, it has been agreed that vitrification in glass will not be considered further on technical grounds. As has also been noted, the low spec MOX immobilisation option has not been pursued further by BNFL for several reasons. Of the 6 immobilisation options examined it is concluded that the 2 options which incorporate the plutonium in a ceramic matrix without any radiation barrier, using either a new facility or a modified SMP offer the best benefits in terms of technical feasibility, minimisation of risk, and environmental impact. On the basis of the preliminary cost estimates so far carried out, it is not possible at this point to discriminate sensibly between any of the immobilisation options in terms of cost alone. All options would require a development programme which needs to focus on process and wasteform.

The initial immobilisation risk review indicates that the uncertainty in project definition (e.g. feed scope, product specification and final geological disposal) and the immaturity of design and development work dominates. There is therefore, insufficient data at present to enable a clear distinction to be made between the immobilisation options.

It should also be borne in mind that, while today's technology and knowledge may consider immobilised material 'irretrievable', new technologies could be developed in the future which may well allow the material to be retrieved, the Pu separated and its energy potential realised.

While recognising that there are still many hurdles to overcome, utilisation as MOX fuel in reactor does have the benefit of using at least some of the energy potential of the stockpile and attracting revenue to help meet costs. Additionally, the Pu is effectively immobilised in the fuel, either within the reactor while it is being irradiated or within the spent fuel following irradiation.

With regard to the choice of reactor, it is agreed that both the Magnox and AGR options are unlikely to prove viable options for Pu disposition. Equally, it is unlikely that Fast Reactors will be able to contribute to the Pu management programme on an acceptable timescale. Scenarios involving all these reactor types have therefore not been pursued further.

The case for use of UK plutonium in overseas LWR reactors is both commercially and politically very sensitive and is very much a matter for the utilities and governments concerned.

The safeguards measures that would need to be applied under the storage or recycling options are for the most part mature and well-developed. The exception is the uncertainty over the detail of safeguards measures that would be applied to irradiated MOX fuel subject to disposal (although the same uncertainty also applies in respect of long-term safeguards arrangements for the disposal of all other irradiated fuel). But there is little doubt that sound safeguards measures can be developed for plutonium in this form. There is also little doubt that processes to immobilise plutonium and for its subsequent storage and disposal could be satisfactorily safeguarded. However, similarly robust measures to those that exist for MOX fabrication and usage are still some way from being fully developed, tested and proven under operational conditions for other disposition processes

The addition of a radiation barrier to an immobilised product would complicate the existing safeguards methods for verifying plutonium oxide or fresh MOX and successful verification would require novel approaches that do not currently exist. The addition of a radiation barrier is also of questionable benefit to the overall security of the plutonium. It may increase the difficulty of successful theft by increasing the intrinsic security of the stored plutonium but there are other ways of achieving adequate security that do not require the vast expense and technological challenge of an artificial radiation barrier. Nonetheless, given the PuWG's view that an alternative approach to the management of plutonium stocks needs to be developed, there would be merit in examining the concept further if other "intrinsic security" arrangements should apply.

BNFL also recognises that the economic case for converting all of the stockpile may not be robust - some of the stockpile may require technically feasible, but costly, pre-treatment prior to manufacture as MOX fuel, and hence immobilisation may be the only tenable option for this material. BNFL, however, in looking at the work which has been carried out internationally, believes that there is still much to do in this area to reach a decision on the most suitable matrix for long term immobilisation and geological disposal. It may be, for example, that the material which is economically questionable with respect to use in reactor, may also require pre-treatment prior to immobilisation.

It is worth noting that the particular implications of the September 11th 2001 terrorist attacks on the US are subject to a review initiated by the UK's regulatory authorities. No further implications on the Pu management options have been considered here.

11. Conclusions

Using information presented to the PuWG in the past, and drawing on BNFL's involvement in international Pu management strategy discussions, this paper has set down the issues surrounding the future management of the UK Pu stockpile. Three principal options which are agreed upon are:

- continued storage as a zero value asset against future use
- immobilisation as waste for long-term and/or indefinite storage then disposal
- recycle as MOX fuel in reactors followed by spent fuel management

Based on the work carried out so far, including BNFL's own work and guidance from the PuWG and the SAP process, BNFL's assessment of these options, and their various sub-options, can be summarised as follows :

1. continued storage is an acceptably safe, secure and safeguarded option for the near future, although it cannot not be viewed as a viable long-term solution (beyond around 25 years)
2. technical and economic uncertainties associated with the relative immaturity of the various immobilisation options mean that immobilisation cannot yet be viewed as an acceptable long-term solution without a significant development programme
3. re-use as MOX fuel in reactor provides an intrinsic level of immobilisation and also has the benefit of yielding energy from the Pu with the associated revenue offsetting costs
4. the possibilities which the inert matrix fuel option may offer in terms of immobilisation, stockpile reduction, energy output and revenue earning are encouraging and will be pursued further.

BNFL supports the option of recycling the majority of the UK stockpile as MOX fuel in reactors, in conjunction with the adoption of a policy of new reactor build in the UK. A part of the UK stockpile may be more effectively dealt with by immobilisation and BNFL continues to support investigations, both internally and through funding of University research programmes, into the most appropriate immobilised form.

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Appendix 1

Immobilisation : Summary and Principal References used in 1998 Literature Study

The work consisted of a literature review and was carried out in the context of international interest in plutonium immobilisation as an option for the disposition of weapons grade plutonium. The information gathered for the review was obtained from an external literature search of commercial and academic patents and papers and an Internet search encompassing data available from international nuclear organisations and laboratories. Over 6000 references were identified many of which contained similar contents (i.e. conference repetitions) and many were 'strategy' papers that also repeated themselves.

The principle references which led to the conclusions of the BNFL team at that time, are attached.

OPTIONS FOR PLUTONIUM DISPOSITION BY IMMOBILISATION (1998)

Summary

Any immobilisation technology must render the plutonium inaccessible to diversion thus the plutonium should be in physical form which is at least as inaccessible for future weapons use as the plutonium in spent fuel from civil nuclear reactors. A further deterrent to proliferation is either to spike the plutonium with other components that provide a chemical or radiological barrier, or to encapsulate the immobilised plutonium package in radioactive glass (ie the can-in-canister concept).

Despite the volumes of literature written about plutonium disposition the immobilisation technologies are not mature, they have not been fully validated using radioactive materials and many issues remain to be resolved. The evidence to date supports the findings from many previous studies on plutonium immobilisation and shows that there have been no further achievements in recent years.

Glass and ceramic wasteforms show the greatest potential for bulk plutonium immobilisation and have undergone the most research, however they both have their advantages and disadvantages. The final choice of wasteform may ultimately depend on the exact remit given for plutonium immobilisation and the criteria chosen for disposition and disposal. Other wasteforms, such as sinter glasses and electrometallics etc, are technically viable but are generally less well developed and are not perceived to show any particular advantages over glass and ceramics, either in terms of processing and/or final wasteform performance (Refs 1, 2).

Further Work

If plutonium immobilisation were ever to be carried out, further work would be required to determine which option would actually be viable on an industrial scale, as there are many outstanding issues that need to be resolved for both the vitrification and the ceramics options. However, whichever option is pursued the following topics need to be addressed.

- Definition of process feeds and flowsheets
- Optimisation of process operational envelopes
- Definition of methods of criticality control and shielding requirements
- Qualification of the wasteform
- Resolution of long term environmental and disposal issues

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Issues:

Cements

- Cementitious grouts are only suitable for encapsulating wastes with very low levels of plutonium contamination [e.g. the treatment of plutonium contaminated material/waste (PCM)], owing to alpha radiolysis which could lead to physical stability problems in the final wasteform.

- Phosphate-based cements may offer some potential for encapsulating wastes containing more plutonium than is acceptable for PCM treatment but significant development work would be required to confirm this view.

Glass/Vitrification

- Glass is likely to be more flexible than ceramics in terms of incorporating impurities and a wider range of wastes.
- Borosilicate glass has been accepted as the international standard for High Level Waste (HLW) immobilisation as a result of four decades of development and some 20 years of actual production of HLW glass. HLW vitrification technology is being used on a production scale and residue (glass and container) specifications have been developed in the form of waste acceptance criteria.
- The base glass matrix for immobilising plutonium has not been optimised.
- The maximum loading achievable in a borosilicate glass is in the range 3-10 wt % Pu depending on the exact base glass chosen and the melting temperature used.
- To immobilise lower levels of plutonium (< 5 wt %) an in-can batch melting process (at ~ 1100°C) and a conventional borosilicate glass would be suitable.
- To immobilise higher levels of plutonium (5-10 wt %) and/or heterogeneous plutonium materials cold crucible melting (at 1400-1500°C) and a lanthanide borosilicate (Löeffler) glass may prove to be a more suitable technology.
- The operators of the HLW vitrification plants around the world do not consider bulk plutonium vitrification to be feasible in their facilities as they are currently engineered.

Ceramics

- Several types of ceramic material offer the potential for immobilising plutonium.
- Synroc (based on naturally occurring titanate minerals) has been developed by the Australian Nuclear Science and Technology Organisation (ANSTO) over many years and has been extensively researched and characterised but it has not yet been used in a fully industrialised and radioactive process. A titanate pyrochlore [$Ca(U,Pu)Ti_2O_7$] derived from Synroc has been chosen by the US DoE for plutonium immobilisation.
- Zirconates and zircons are also possibilities but have undergone far less research and development.
- High plutonium loadings (possibly up to ~ 25 wt %) could be achieved in a wasteform of minimal volume and good chemical durability.
- Ceramics may be preferred for ensuring product integrity against criticality excursions over extended periods of time, owing to their higher resistance to chemical attack (ie water ingress in the repository).

- Ceramics can immobilise fairly clean and homogeneous wastes but there may be a trade-off with plutonium incorporation levels if differing types and quantities of impurities have to be accommodated.
- Ceramics are not suitable for treating miscellaneous and/or heterogeneous wastes and residues.
- Production processes similar to those used for producing mixed oxide fuel could be developed for immobilising plutonium in a ceramic wasteform.
- Criticality control is considered to be easier in preparing crystalline ceramics than it is in preparing glass monoliths.

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Appendix 2

i. Immobilisation BPEO Study Criteria

Criteria	Attribute	Rating definition
Cost	Lifetime Cost	H = High Cost
	Financial risk	H = High Risk
Stakeholder Preference	Safeguards	H = Highly acceptable
	Regulators	H = Highly acceptable
	Security	H = Highly secure
	Pub/shareholder	H = Highly acceptable
Technical Viability	Ease of operation	H = Easy to operate
	Lifetime of Plant	H = Plant is available
	Chance of success	H = Proven to be successful
	Development Issues	H = Option developed
	Volume of interim store	H = High volume store required
Environment, Health & Safety	Worker Health	H = High additional dose
	Discharges	H = High discharge volumes
	Solid Waste Disposal	H = High suitability for disposal
	Vol. of wastes	H = minimum volumes of wastes generated
	Sustainability	- H = represents a long-term sustainable option
	Repository Compatibility	H = Final product will be compatible

ii. Recycle in reactors assessment criteria

Technical
- fuel performance and fuel rod design
- fuel assembly design and in-core fuel management, including core physics
- transport
- spent fuel handling
- reactor pond storage

Utilisation
- Pu throughputs
- station lifetimes
- number of reactors required/available

Licensing
- UK knowledge & experience
- World knowledge & experience
- timescales

Manufacturing
- capacities/throughputs
- capabilities
- experience

Safeguards and Security
- any reactor specific differences
- possibility of greater requirement for Euratom/IAEA presence

Political Acceptability
- public perception
- energy requirements

UK Government Control
- UK project
- UK driven
- UK controlled
- reliance on other companies/nations

Economics and Commercial Viability
- commercial risk
- commercial spin-offs

Appendix 3

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Annex 4: Detailed Output from SAP

Immobilisation Options I1 – New Build Immobilisation Plant

Assumptions:

Note that assumptions as defined in the SAP analysis are things which have to be true if the option as defined is to proceed; they are used to identify uncertainties for which investigations or explorations are needed. The listing of an assumption here does not imply that the PuWG believes the assumption is, or is likely, to be true.

Interim PuO_2 Storage

1) Adequate PuO_2 storage is available for use over medium term

Manufacture

1) All PuO2 stock can be immobilised in some form
2) New build will be at Sellafield
3) New immobilisation plant operates satisfactorily

Waste Management

1) Pu, once immobilised, would be suitable for long term storage at Sellafield
2) Waste form qualification system for Pu wastes is in place (ref: Waste Working Group)
3) Pu waste forms meet qualification requirements
4) suitable storage containers and buildings can be arranged

Transport

1) No transport is needed off Sellafield site unless/until required for final disposal

Societal Issues

1) Immobilisation is preferred to the current situation by the public (ie. Publicly acceptable)
2) There is no significant public opposition, either locally or nationally
3) Long term storage of immobilised Pu is, and remains, publicly acceptable
4) Continued interim storage of PuO2 remains publicly acceptable for long enough to implement the option chosen

Costs and Funding

1) This option is compatible with policy, is cost effective and would attract adequate funding

Policy

1) As a matter of policy, no Pu is required for use in reactors, or for strategic stock
2) Indefinite storage of PuO_2 is unacceptable from a policy viewpoint
3) Immobilisation can be formally justified (EURATOM directive, UK legislation etc.)

Regulation

1) All relevant authorisations and licences can be obtained
2) Indefinite storage of PuO_2 is unacceptable from a regulatory viewpoint
3) Immobilisation can be formally justified (EURATOM directive, UK legislation etc.)
4) Immobilisation without an external radiological barrier provides sufficient security

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Manufacture (I1)	Develop criteria for product specification By 2006	Evaluate alternative waste forms (including feedstock assessments) congruent with future waste management strategy, safety, safeguards and security requirements and technical feasibility of manufacture		if you can't meet programme timetable and requirements go for • continued storage (pending re-design) • use of SMP for MOX production • reactor based options
		Evaluate optimum Pu loading for disposal and security purposes	Agree the product spec.	
	Develop plant specification (including storage)	Establish what proportion of the stockpile can be immobilised without reconditioning		
		Establish what process stages you need to achieve product spec. covering all Pu stocks	Decide size and spec of containers	
		Establish plant capacity and programme requirements		
		Establish if there is space at Sellafield for the plant and associated infrastructure	Decide if you need a pilot plant	
		Optimise plant spec (including infrastructure) to maximise safeguards & security benefits e.g. on site movement is minimised	Design and then build the plant	

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Regulation (I1)	Establish timescale and feasibility under current regulations (see explorations)	Explore likelihood of successful outcome to planning application As part of above, carry out initial environmental impact assessments (EIA) at Sellafield (nb link to societal issues) Consult regulators to establish likely requirements/likelihood of successful application for radioactive substances act consents, re-licensing, approved safety cases etc Establish current policy: responsibility and procedure on justification processes Consult relevant European regulators regarding requirements/likelihood of successful application under EURATOM Article 37 Explore availability of space and likely planning conditions on extended storage ofimmobilised product at Sellafield Confirm policy interpretation that immobilisation without an external radiological barrier provides sufficient security	Decide if this option is feasible if the timescales are too long (ie outside the lifetime of existing storage buildings Proceed to full EIA/planning application/licensing applications/Article 37 etc. (nb exactly who is carrying out these activities may depend on contractual arrangements - see costs, funding and contracts	If you can't get necessary approvals in time for new plant or storage facilities consider extending existing storage of PuO_2 – upgrade storage or defer to other options If unsuccessful, appeal or go to other options

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Waste Management (i.e. immobilised Pu) (I1)	Confirm that interim storage of immobilised product is acceptable (***this applies to every option***) Confirm that the product and its transportation does not foreclose foreseeable long term management options	Assess the requirements of storage containers and storage facilities capacity for this product at Sellafield Investigate the planning and socio economic implications of extended storage of the product at Sellafield Draw down lessons from international R&D practice	Decide size and spec of store Seek permissions required	If the stores cannot be consented to timescale: • Defer product programme and continue to store as Pu • Consider other options Note: consider a recommendation to ensure the MRWS consultation covers these issues

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Policy (I1)	Confirm that current policy does not hinder or stop this option Engage with government on Energy and waste management reviews.	Consider if the energy review has any implications for this option (e.g. strategic stock/reserve, attitude to or conditions for new build?) Monitor UK energy policy Monitor UK waste management policy development Monitor EU policy developments Establish current policy: responsibility and procedure on justification processes – NB this will carry across to other options	Make a case for justification	If the outcome of these policy reviews is such that it prevents this option then go for alternative options If you cannot make justification case go to other options

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Societal Issues (I1)	Identify stakeholders and establish communication with them e.g. forum Find out what the societal issues are with this option (review previous processes to anticipate what the issues are) e.g.: • change from interim storage to long term waste management • increased requirement for stores and need for planning consents • change in employment patterns Assess socio-economic impacts of option and, if appropriate, possible means of amelioration	Engage stakeholders, wider public and local community in an ongoing dialogue so that they understand the implications for them of this option and in order that the developer can understand their concerns Measure opinions locally and nationally and assess trends Establish current community attitudes to the existing Pu storage arrangements Identify what you need to do to promote this option (know the positive and the negative implications of this option) ***Notes***: • The importance of involving the community in strategic decisions (generic across all SAPs) • The value of involving the local community at sites (generic across all SAPs) • Tension between national and local interests (generic across all SAPs)	Adapt implementation programme/strategy in light of monitoring Engage community in a process that informs them why the decisions have been taken and what the impact on their community will be	If trends negative, revisit explorations e.g. amelioration

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Costs, Funding & Contracts (I1)		Establish the cost of this option and your approach to contract placement Establish the funding basis for this option ie who will pay Explore synergies with other parties e.g. BE etc Establish the risks, operator responsibilities, liabilities in going in this direction	Decide on preferred contractual basis: form or design of contracts Enter into negotiation to establish contract	If costs are excessive or can't agree contracts revert to other options

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Transport (I1)		Confirm existing assets can transport product, or New assets can be designed for all stages of cycle on Sellafield site Check safety, safeguards and security arrangements for transport within Sellafield site Consider whether integrated plant design can reduce transport requirements	Decide whether or not to procure new assets or upgrade existing assets Decide whether or not to change procedures for safety, safeguards and security	

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Interim Pu storage (I1)	Confirm current storage capacity and required capacity	Determine if Pu storage will constrain the programme, having regard to when the option starts and its duration Assess whether existing storage is currently safe and structurally secure against risks and whether it will meet safety, security and safeguards standards for the required storage lifetime. Establish required actions to ensure that safety security and safeguards standards are met	Decide what actions might have to be taken to ensure continued safe, secure and safeguarded storage (This could include improving storage conditions)	Upgrade or build new stores (NB design studies are underway) Bring forward alternative options programmes if threat assessment warrants it.

Immobilisation Options I2 –Immobilisation as low spec MOX

Assumptions:

Note that assumptions as defined in the SAP analysis are things which have to be true if the option as defined is to proceed; they are used to identify uncertainties for which investigations or explorations are needed. The listing of an assumption here does not imply that the PuWG believes the assumption is, or is likely, to be true.

Manufacture

1) All PuO2 stock can be immobilised in some form
2) SMP operates satisfactorily and produces MOX suitable for overseas customers
3) SMP can be modified to produce low spec MOX
4) SMP operates satisfactorily in modified form

Waste Management

1) Pu, once immobilised as low spec MOX, would be suitable for long term storage at Sellafield
2) Waste form qualification system for Pu wastes is in place (ref: Waste Working Group)
3) Low spec MOX waste forms meet qualification requirements
4) suitable storage containers and buildings can be arranged

Transport

1) No transport is needed off Sellafield site unless/until required for final disposal

PuO_2 Storage

1) Adequate PuO2 storage is available over medium to long term

Societal Issues

1) Immobilisation as low spec MOX is preferred to the current situation by the public (ie. Publicly acceptable)
2) There is no significant public opposition, either locally or nationally
3) Long term storage of low spec MOX is, and remains, publicly acceptable
4) Continued interim storage of PuO2 remains publicly acceptable for long enough to implement the option chosen

Costs and Funding

1) This option is compatible with policy, is cost effective and would attract adequate funding

Policy

1) As a matter of policy, no Pu is required for use in reactors, or for strategic stock
2) Indefinite storage of PuO_2 is unacceptable from a policy viewpoint
3) Immobilisation as low spec MOX can be formally justified (EURATOM directive, UK legislation etc.)

Regulation

1) All relevant authorisations and licences can be obtained
2) Indefinite storage of PuO_2 is unacceptable from a regulatory viewpoint
3) Immobilisation as low spec MOX can be formally justified (EURATOM directive, UK legislation etc.)
4) Immobilisation as low spec MOX without an external radiological barrier provides sufficient security

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Manufacture (I2)	Develop criteria for product specification	Evaluate alternative MOX forms (including feedstock assessments) congruent with future waste management strategy, safety, safeguards and security requirements and technical feasibility of manufacture • U content • Neutron absorbers	Agree the product spec. Decide size and spec of containers	If you can't meet programme timetable and requirements go for • build an additional production line onto SMP • continued storage (pending re-design) • new build immobilisation plant • reactor based options
		Investigate synergy with management of DU 'tails' and stocks including conversion capacity for HEX to Oxide?	Decide plant modifications required	
	Develop plant modification specification (including storage)	Evaluate optimum Pu & neutron absorber loading for disposal and security purposes Establish what proportion of the stockpile can be immobilised without reconditioning Establish what process stages you need to achieve product spec. covering all Pu stocks Establish plant capacity, timing of availability in SMP, and programme requirements Establish whether low spec MOX could be produced alongside MOX fuel (existing or additional production lines)	Determine programme for plant modification and production taking account of requirements for production of MOX fuel in SMP	

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Regulation (I2)	Establish timescale and feasibility under current regulations (see explorations)	Establish whether planning permission necessary for modified plant and MOX stores, or just MOX stores. Explore likelihood of successful outcome to planning application As part of above, carry out initial environmental impact assessments (EIA) at Sellafield (nb link to societal issues) Consult regulators to establish likely requirements/likelihood of successful application for radioactive substances act consents, re-licensing, approved safety cases etc Establish current policy: responsibility and procedure on justification processes Consult relevant European regulators regarding requirements/likelihood of successful application under EURATOM Article 37 Explore availability of space and likely planning conditions on extended storage of low spec MOX product at Sellafield Confirm policy interpretation that immobilisation as MOX without an external radiological barrier provides sufficient security	Decide size and spec of store Decide size and spec of containers Seek permissions required	If the stores cannot be consented to timescale: • Defer product programme and continue to store as Pu • Consider other options Note: consider a recommendation to ensure the MRWS consultation covers these issues

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Waste Management (i.e. low spec MOX) (I2)	Confirm that interim storage of low spec MOX product is acceptable (this applies to every option) Confirm that the product and its transportation does not foreclose foreseeable long term management options.	Assess the requirements of storage containers and storage facilities capacity for this product at Sellafield including SMP export facility. Investigate the planning and socio economic implications of extended storage of the product at Sellafield Drawn down lessons from international R&D	Decide size and spec of store Seek permissions required	If the stores cannot be consented to timescale: • Defer product programme and continue to store as Pu • Consider other options Note: consider a recommendation to ensure the MRWS consultation covers these issues

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Policy (I2)	Confirm that current policy does not hinder or stop this option Engage with government on Energy and waste management reviews.	Consider if the energy review has any implications for this option (e.g. strategic stock/reserve, attitude to or conditions for new build?) Monitor UK energy policy Monitor UK waste management policy development Monitor policy on management of DU stocks and 'tails' Monitor EU policy developments Establish current policy: responsibility and procedure on justification processes – NB this will carry across to other options	Make a case for justification	If the outcome of these policy reviews is such that it prevents this option then go for alternative options If you cannot make justification case go to other options

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Societal Issues (I2)	Identify stakeholders and establish communication with them e.g. forum Find out what the societal issues are with this option (review previous processes to anticipate what the issues are) e.g.: • change from interim storage to long term waste management • increased requirement for stores and need for planning consents • change in employment patterns Assess socio-economic impacts of option and, if appropriate, possible means of amelioration	Engage stakeholders, wider public and local community in an ongoing dialogue so that they understand the implications for them of this option and in order that the developer can understand their concerns Measure opinions locally and nationally and assess trends Establish current community attitudes to the existing Pu storage arrangements Identify what you need to do to promote this option (know the positive and the negative implications of this option) ***Notes***: • The importance of involving the community in strategic decisions (generic across all SAP's) • The value of involving the local community at sites (generic across all SAP's) • Tension between national and local interests (generic across all SAPs)	Adapt implementation programme and strategy in light of monitoring Engage community in a process that informs them why the decisions have been taken and what the impact on their community will be	If trends negative, revisit explorations e.g. amelioration

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Costs, Funding & Contracts (I2)		Establish the cost of this option and your approach to contract placement Establish the funding basis for this option ie who will pay Explore synergies with other parties e.g. BE, owners of depleted U stocks and tails Establish the risks, operator responsibilities, liabilities in going in this direction	Decide on preferred contractual basis: form or design of contracts Enter into negotiation to establish contract	If costs are excessive or can't agree contracts revert to other options

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Transport (I2)		Confirm existing assets can transport product, or New assets can be designed for all stages of cycle on Sellafield site Check safety, safeguards and security arrangements for transport within Sellafield site Consider whether integrated plant design can reduce transport requirements	Decide whether or not to procure new assets or upgrade existing assets Decide whether or not to change procedures for safety, safeguards and security	

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Interim Pu storage (I2)	Confirm current storage capacity and required capacity	Determine if Pu storage will constrain the programme, having regard to when the option starts and its duration Assess whether existing storage is currently safe and structurally secure against risks and whether it will meet safety, security and safeguards standards for the required storage lifetime. Establish required actions to ensure that safety security and safeguards standards are met	Decide what actions might have to be taken to ensure continued safe, secure and safeguarded storage (This could include improving storage conditions)	Upgrade or build new stores (NB design studies are underway) Bring forward alternative options programmes if threat assessment warrants it.

Reactor Options R2 – UK Pu in existing UK reactors

Assumptions

Note that assumptions as defined in the SAP analysis are things which have to be true if the option as defined is to proceed; they are used to identify uncertainties for which investigations or explorations are needed. The listing of an assumption here does not imply that the PuWG believes the assumption is, or is likely, to be true.

Interim PuO_2 Storage

1) Adequate PuO2 storage is available for use over medium term

Manufacturing Fuel

1) All Pu stock can be used in reactors subject to actions identified in the quality review of material.
2) MOX fuel will be made in SMP
3) SMP is commissioned successfully and produces MOX of an acceptable quality for overseas customers
4) There will be no irreparable breakdowns
5) There will be sufficient fuel manufacturing capacity available to convert the stockpile within a reasonable time.

Reactor Operation

1) There will be a sufficient reactor capacity/ customer base to consume the stockpile within a timeframe that is compatible with fuel manufacture
2) Reactor modifications (for existing reactors) are feasible and can be licensed and implemented within programme timescales
3) Appropriate security/ safety measures are in place

Waste Management

1) Spent MOX fuel is not reprocessed
2) Spent MOX fuel is suitable for long term storage at reactor sites or Sellafield
3) Waste form qualification system for Pu wastes is in place (ref: Waste Working Group)
4) Spent MOX waste forms meet qualification requirements
5) Suitable storage containers and buildings are available.

Transport

1) For non-Sellafield reactor options, the transport of fresh MOX fuel and, if required, spent MOX fuel, continues to meet the requirements of safety and security regulators
2) The requirements of the safety, safeguards and security regulators are demonstrably adequate to control the risks associated with MOX transport
3) For non-Sellafield reactor options, the transport of fresh MOX and, if required, spent MOX fuel, is not disrupted/ prevented by public opposition
4) Current national & international policy re. MOX fuel transport do not change

Policy

1) Ownership of Pu, spent fuel and other material is clear
2) MOX utilisation is seen as an acceptable Pu management strategy
3) Manufacture and use of MOX fuel can be formally justified as a Pu management strategy

Regulation

1) Planning and consent procedures are streamlined and stable
2) All relevant authorisations and licenses can be obtained

Societal Issues

1) There is insufficient public opposition, either locally, nationally or internationally, to prevent MOX fuel manufacture and use in reactors
2) Storage/ processing will be acceptable to the community at Sellafield
3) Long-term storage of spent MOX fuel is, and remains, publicly acceptable.
4) Some form of public engagement has taken place regarding the option
5) Continued interim storage of PuO2 remains publicly acceptable for long enough to implement the chosen option

Costs and Funding

1) If Pu is not classified as a waste, a commercial case can be made for MOX fuel use
2) If Pu is classified as a waste, reactor options are cost effective and would attract funding

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Fuel manufacture (R2)	Confirm currently assumed lifetimes and availability of AGR & LWR reactors and MOX core capacity to establish Pu burn rate	Undertake a quality review of the existing material in relation to existing UK reactors selected to establish how much is suitable/will be suitable during reactor lifetimes. What proportions suitable for AGR? What proportions for LWR?	***Note*** Feed into reactor availability and SMP availability Decide what type of fuel and what quantity to manufacture (AGR or LWR)	If some PuO2 cannot be converted into fuel • continue interim store of PuO2 • treat as waste including immobilisation In the event SMP doesn't perform or irreparable breakdown: • Build another line/plant on SMP. • Seek to get fuel manufactured overseas.
	Confirm SMP operating satisfactorily.	Examine feasibility timescale and costs for treating material that isn't suitable (i.e. make it suitable).	Decide whether the unsuitable PuO2 is to be treated for reactor use and select process.	
	Confirm capacities available when needed	Review performance of SMP • Does it make quality fuel? • Does it produce fuel quickly enough? • Does it meet regulatory requirements?	Decide whether any improvements are required to SMP.	If unable to meet capacity (see lifetime Business Case) requirements seek: • Re scheduling of existing contracts for MOX fuel manufacture • SMP Lifetime extension • SMP 2 • Manufacture elsewhere?
		Determine available capacity of SMP with respect to: • Fuel type/usage profile • Lifetime of SMP and reactors • SMP modifications possibly required • SMP2 required?	Decide whether to modify/extend lifetime SMP/build SMP2	If can't manufacture fuel • continue interim store of PuO2 • treat as waste including immobilisation

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Reactor operation (R2)	confirm currently assumed lifetimes and availability of AGR & LWR reactors and MOX core capacity Enter into discussions with BE about Pu burning in its reactors. (Link to costs and funding) (Commercial framework is a key consideration in determining whether and how option could proceed	Explore the possibility of extending reactor lifetimes to accommodate burning the Pu stockpile Examine the potential for increasing the core capacity of reactors to burn the Pu stockpile Establish the rate of utilisation of Pu per reactor per year Establish what reactor modifications are needed to burn MOX. Identify what, if any, additional safety, safeguards and security measures are necessary. Determine what licensing requirements might be necessary (link to policy and regulation). Establish what commercial arrangements would need to be put in place. (Link to costs and funding) Estimate the likely start date for reactor burning of MOX	Decide whether to burn MOX in either / or both AGRs and LWRs and programme details. (link to fuel manufacture) Determine the latest start date for viability of this option	If we can only burn a proportion of the MOX in existing UK reactors consider parallel programmes covering: • New build reactors. • Send fuel overseas. • storage and or immobilisation of Pu options If we can't burn enough MOX to make it viable or none at all in existing UK reactors consider alternative programmes covering: • New build reactors. • Send fuel overseas. • storage and or immobilisation of Pu options (note: these contingencies are not in any order of priority)

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Regulation (R2)	Establish timescale and feasibility under current regulations Check if EURATOM article 37 (EU discharge consents) submission is required Check if new or revised radioactive substances act (RSA) authorisations are required	Check existing planning consents for storage facilities at Sellafield regarding time spans Check existing planning consents for storage facilities at other sites regarding timespans Check available space at Sellafield and existing reactor sites for storage Monitor developments in convergence of planning and other consents Determine what licensing requirements might be necessary re. reactor modifications or lifetime extensions. Explore likely planning and regulatory conditions on extended storage of irradiated fuel at selected site(s) including centralised store and how you would address them	Decide how planning and regulatory requirements are to be accommodated in the overall design of the option Decide if this option is feasible or if the timescales are too long (ie SMP not available to make this MOX fuel within Reactor lifetimes) (nb: exactly who is carrying out these activities may depend on contractual arrangements – see costs funding and contracts) If it is feasible, prepare and make applications	If you can't get necessary approvals in time for modifying reactors or building storage facilities Consider long term storage of PuO2, use in overseas reactors or pursue immobilisation option If unsuccessful, appeal or go to other options

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Waste Management (i.e. spent MOX) (R2)	Confirm that interim storage of spent MOX is acceptable (this applies to every option) Confirm whether spent MOX fuel forecloses foreseeable long term management options (Including at optimum burn up) Confirm if the interim wet or dry storage is consistent with ultimate disposal of the fuel	Assess the storage medium and storage capacity needed at reactor sites and at Sellafield (potentially including the need to take lifetime arisings of spent MOX fuel at each reactor site) Explore pros and cons of central Vs reactor site storage (including transport issues) Establish the storage requirements at the reactor sites. If fuel stores are already available are they suitable or can they be made so? Modifications to storage medium e.g. to cooling systems, to enable greater capacity to match volume Investigate the planning and socio economic implications of extended storage of irradiated MOX at all sites Look at other EU practice to learn from their experience	Take account of the results of exploration and decide whether to have a central store Decide to store wet or dry Decide where to store (taking into account all transport issues) Decide how to store Decide assets required Seek permissions required	Control manufacture of fuel to match availability of storage Continue present storage of PuO_2 until there is policy clarity on waste form system ***Note***: consider a recommendation to ensure the MRWS consultation covers these issues

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Policy (R2)	Confirm that current policy does not hinder or stop this option Engage with government on Energy and waste management reviews.	Consider if the energy review has any implications for this option (e.g. strategic stock/reserve, attitude to or conditions for new build?) Monitor UK energy policy Monitor UK waste management policy development Monitor EU policy developments Monitor and seek to clarify Government policy on justification process (including storage implications)	Make a case for justification	If the outcome of these policy reviews is such that it prevents this option then go for alternative options If you cannot make justification case go to other options

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Societal Issues (R2)	Identify stakeholders and establish communication with them e.g. forum Find out what the societal issues are with this option (review previous processes to anticipate what the issues are) e.g. • Extended storage onsite, construction of new stores • Extension of station lifetimes, safety concerns v. employment • Increase in Pu (MOX) transport around the UK • Implications of change in fuel type • Is nuclear power environmentally beneficial or environmentally harmful? Assess socio-economic impacts of option and, if appropriate, possible means of amelioration	Engage stakeholders, wider public and local community in an ongoing dialogue so that they understand the implications for them of this option and in order that the developer can understand their concerns Measure opinions locally and nationally and assess trends Establish current community attitudes to the existing Pu storage arrangements Identify what you need to do to promote this option (know the positive and the negative implications of this option) ***Notes***: • The importance of involving the community in strategic decisions (generic across all SAP's) • The value of involving the local community at sites (generic across all SAP's) • Tension between national and local interests (generic across all SAPs)	Adapt implementation programme/strategy in light of monitoring Engage community in a process that informs them why the decisions have been taken and what the impact on their community will be	If trends negative, revisit explorations e.g. amelioration

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Costs, Funding & Contracts (R2)	Establish a collaborative approach between BE/BNFL to establish the feasibility (commercial, economic, technical and political) of using Pu stockpile in existing reactors, including the explorations in this SAP (nb: as early as possible does Govt/LMA need to be brought in?) BE / BNFL to investigate the trade off between reprocessing AGR fuel and burning Pu	In the case where BE burns non BE Pu investigate all contractual issues (including the ownership issues relating to Pu and radioactive wastes) Explore the potential contractual arrangements Establish the costs and funding for this MOX fuel option (spectrum is from profitable to subsidised) Establish the risks, operator responsibilities, liabilities in going in this direction	Decide on the preferred contractual basis Enter into negotiation to establish contract ***Note***: On the LMA model the whole operation would necessarily be contracted to one third party or another)	If can't establish the collaborative approach, with BE go for other options If can't agree contract revert to other options (build own reactor, immobilise it or get govt. subsidy because of UK policy) If the commercial assessment is bad, decide whether it is possible to do it on a subsidised basis for policy reasons

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Transport of new fuel (R2)	Confirm what existing modes and approved routes and assets are available to transport MOX to UK reactors Ensure stakeholders understand transport arrangements including safety, safeguards & security measures nb: link to societal issues	Review suitability of modes, routes and assets for transport of AGR & LWR MOX to potential sites including safety, security and safeguard requirements and actions required to address any shortfall. If increased quantities of MOX are transported - are current arrangements including standards robust enough (to satisfy political acceptability) Monitor stakeholder and government attitudes to fuel transport and its risks Establish what measures eg exercises, are necessary to publicly demonstrate the adequacy of safety, safeguards and security risks management (joint fact finding?) Investigate availability /capacity of contingencies.	Decide modes, routes and assets that will be used. Commit to construction of any new assets required (mode or route change?) Take whatever actions are required following review	Increase safety, safeguards and security measures where practical In the event of a route being lost switch routes. In the event of a loss of mode: look to an alternative mode (could have impact on assets i.e. flasks, cranes, transport assets etc) • or store and / • or stop fuel production • or build new reactor at Sellafield (in long term situation)

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Transport of spent MOX fuel (R2)	Confirm what modes approved routes and assets are available to transport spent MOX from existing UK reactor sites sites Ensure stakeholders understand transport arrangements including safety security and safeguards measures. nb: link to societal issues	Review suitability of modes routes and assets for transport of spent AGR & LWR MOX including safety, security and safeguard requirements and actions required to address any shortfall Including to meet final dry waste form requirement Monitor stakeholder and government attitudes to spent fuel transport	Feed in the results of the review of spent MOX transport into waste management decision making on storage locations If transport is required, decide modes, routes and assets that will be used	If you can't transport, build sufficient storage capacity for lifetime arisings at reactor site(s)

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Interim Pu storage (R2)	Confirm current storage capacity and required capacity	Determine if Pu storage will constrain the programme, having regard to when the option starts and its duration Assess whether existing storage is currently safe and structurally secure against risks and whether it will meet safety, security and safeguards standards for the required storage lifetime. Establish required actions to ensure that safety security and safeguards standards are met	Decide what actions might have to be taken to ensure continued safe, secure and safeguarded storage (This could include improving storage conditions)	Upgrade or build new stores (NB design studies are underway) Bring forward alternative options programmes if threat assessment warrants it.

Reactor Options R3– UK Pu in new build UK reactors

Assumptions

Note that assumptions as defined in the SAP analysis are things which have to be true if the option as defined is to proceed; they are used to identify uncertainties for which investigations or explorations are needed. The listing of an assumption here does not imply that the PuWG believes the assumption is, or is likely, to be true.

Interim PuO_2 Storage

1) Adequate PuO_2 storage is available for use over medium term

Manufacturing Fuel

1) All Pu stock can be used in reactors subject to actions identified in the quality review of material.
2) MOX fuel will be made in SMP
3) SMP is commissioned successfully and produces MOX of an acceptable quality for overseas customers
4) There will be no irreparable breakdowns
5) There will be sufficient combination of fuel manufacturing and reactor capacity to convert the stockpile within a reasonable time
6) SMP will have sufficient lifetime to manufacture fuel taking account of timescale for reactor construction and operation.

Reactor Options

1) New build capacity will be sized by design to consume Pu stockpile in a reasonable time
2) New build will be at an existing licensed nuclear site
3) Appropriate security/ safety measures are in place

Waste Management

1) Spent MOX fuel is not reprocessed
2) Spent MOX fuel is suitable for long term storage at reactor sites or Sellafield
3) Waste form qualification system for Pu wastes is in place (ref: Waste Working Group)
4) Spent MOX fuel meets waste qualification requirements
5) Suitable storage containers and buildings can be arranged.

Transport

1) For non-Sellafield reactor options, the transport of fresh MOX fuel and, if required, spent MOX fuel, continues to meet the requirements of safety and security regulators
2) The requirements of the safety, safeguards and security regulators are demonstrably adequate to control the risks associated with MOX transport
3) For non-Sellafield reactor options, the transport of fresh MOX and, if required, spent MOX fuel, is not disrupted/ prevented by public opposition
4) Current national & international policy re. MOX fuel transport do not change

Policy

1) Outcome of energy review facilitates new reactor build
2) Ownership of Pu, spent fuel and other material is clear
3) MOX utilisation is seen as an acceptable Pu management strategy
4) Manufacture and use of MOX fuel can be formally justified as a Pu management strategy

Regulation

1) Planning and consent procedures are streamlined and stable
2) All relevant authorisations and licenses can be obtained

Societal Issues

1) New reactor build is publicly acceptable at at least one site
2) There is insufficient public opposition, either locally, nationally or internationally, to prevent MOX fuel manufacture and use in reactors
3) Storage/ processing will be acceptable to the community at Sellafield
4) Long-term storage of spent MOX fuel is, and remains, publicly acceptable.
5) Some form of national public engagement has taken place regarding the option
6) Continued interim storage of PuO2 remains publicly acceptable for long enough to implement the chosen option

Costs and Funding

1) If Pu is not classified as a waste, a commercial case can be made for MOX fuel use
2) If Pu is classified as a waste, reactor options are cost effective and would attract adequate funding

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Fuel manufacture (R3)	Confirm MOX core capacity and 'burn rate' of selected reactor designs Confirm SMP operating satisfactorily. Confirm capacities available when needed	Undertake a quality review of the existing material in relation to selected reactor type. How much is suitable/will be suitable at the time reactors are available? Examine feasibility timescale and costs for treating material that isn't suitable (i.e. make it suitable). Review performance of SMP does it make quality fuel? Does it produce fuel quickly enough? Does it meet regulatory requirements? Determine lifetime and available capacity of SMP with respect to: - Fuel type/usage profile - Timescale for reactor build and operation - SMP modifications possibly required - SMP 2 required?	***Note*** Feed into reactor availability and SMP availability Decide what type of fuel and what quantity to manufacture (AGR or LWR) Decide whether the unsuitable PuO2 is to be treated for reactor use and select process. Decide whether any improvements are required to SMP. Decide whether to modify/extend lifetime SMP/build SMP2	In the event SMP doesn't perform or irreparable breakdown: • Build another line/plant on SMP. • Seek to get fuel manufactured overseas. If some PuO2 cannot be converted into fuel • continue interim store of PuO2 • treat as waste including immobilisation If unable to meet capacity (see lifetime Business Case) requirements seek: • Re-scheduling of existing contracts for MOX fuel manufacture • SMP Lifetime extension • SMP 2 • Manufacture elsewhere..? If can't manufacture fuel • cancel plans for reactor construction • continue interim store PuO2 • treat as waste including immobilisation

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Reactor design, construction and operation (R3)	Include assessment of Pu burning in existing BE/BNFL 'collaboration' And/or Consider whether BNFL or LMA would wish to build and operate new reactor(s) for Pu burning (nb link to costs and funding) (nb 'who builds and operates' and 'under what commercial framework' are key considerations determining whether, and how, the option could proceed)	Establish preferred reactor design for burning MOX taking into account optimum fuel burn up rate Establish the feasible/preferred rate of utilisation of Pu Establish likelihood of obtaining planning consents for new development (link to policy and regulation, societal issues). Establish preferred site(s) for construction (link to policy and regulation, societal issues). Identify what safety, safeguards and security measures are necessary. Determine what licensing requirements might be (link to policy and regulation). Establish what commercial arrangements would need to be put in place (link to costs and funding) Estimate the likely start date for reactor burning of MOX	Decide reactor type, numbers of units and site(s) for construction (link to policy and regulation, societal issues). Decide how much of the stockpile its going to be possible to burn given numbers, capacity and lifetimes of reactors which it is feasible to construct Determine the earliest likely start date for this option Decide your preferred programme (what you are going to do and when)	If we can only burn a proportion of the MOX in new build UK reactors consider parallel programmes covering: • Existing UK reactors. • Send fuel overseas. • storage and or immobilisation of Pu options If no new build is feasible consider alternative programmes covering: • Existing UK reactors. • Send fuel overseas. • Storage and or immobilisation of Pu options (nb: these contingencies are not in any order of priority)

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Regulation (R3)	Establish timescale and feasibility under current regulations Initiate appropriate and transparent site selection process (see explorations)	Explore likelihood of successful outcome to planning application (nb may affect site selection) As part of above, carry out initial environmental impact assessments (EIA) at candidate sites (nb link to societal issues) Consult regulators to establish likely requirements/likelihood of successful application (e.g. Radioactive Substances Act) for authorisations, approvals safety cases etc Consult relevant European regulators e.g. regarding requirements/likelihood of successful application under EURATOM Article 37 Explore likely planning and regulatory conditions on extended storage of irradiated fuel at selected site(s) including possible centralised store and how you would address them Monitor developments in convergence of planning and other consents	Decide how planning and regulatory requirements are to be accommodated in the overall design of the option Decide if this option is feasible if the timescales are too long (i.e. option not likely to be available soon enough, within the lifetime of SMP etc.) (Applies to all options) Conclude site selection process and proceed to full EIA/planning application/licensing applications/Article 37 etc. (nb exactly who is carrying out these activities may depend on contractual arrangements - see costs, funding and contracts)	If you can't get necessary approvals in time for building reactors or storage facilities consider long term storage of PuO_2, use in existing UK reactors, use in overseas reactors, or pursue immobilisation option If unsuccessful, amend proposals, appeal or go to other options

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Waste Management (i.e. spent MOX) (R3)	Confirm that interim storage of spent MOX is acceptable (this applies to every option) Confirm whether spent MOX fuel (including at optimum burn up) forecloses foreseeable long term management options (Including at optimum burn up) Confirm if the interim wet or dry storage is consistent with ultimate disposal of the fuel	Assess the storage medium and storage capacity needed at reactor site(s) and at Sellafield (potentially including the need to take lifetime arisings of spent MOX fuel at each reactor site) Explore pros and cons of central vs reactor site storage (including transport issues) Establish the storage requirements at the reactor sites. If fuel stores are already available, are they suitable or can they be made so? Modifications to storage medium e.g. to cooling systems, to enable greater capacity to match volume Investigate the planning and socio-economic implications of extended storage of irradiated MOX at selected site(s) Look at other EU practice to learn from their experience	Decide to store wet or dry Decide where to store (taking into account all transport issues) Decide how to store Decide assets required Seek permissions required	Control manufacture of fuel to match availability of storage Continue present storage of Pu O2 until there is policy clarity on waste form system ***Note:*** consider a recommendation to ensure the MRWS consultation covers these issues

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Policy (R3)	Confirm that current policy does not hinder or stop this option Engage with government on Energy and waste management reviews.	Consider if the energy review has any implications for this option (e.g. strategic stock/reserve, attitude to or conditions for new build?) Monitor UK energy policy Monitor UK waste management policy development Monitor EU policy developments Monitor and seek to clarify Government policy on justification process (including storage implications)	Make a case for justification	If the outcome of these policy reviews is that it prevents this option then go for alternative options If you cannot make justification case go to other options

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Societal Issues (R3)	Identify stakeholders and establish communication with them e.g. forum Find out what the societal issues are with this option (review previous processes to anticipate what the issues are) e.g.: • Possibility of extended storage of spent MOX onsite, construction of new stores • Extension of lifetimes of existing sites safety concerns v. employment • Increase in Pu (MOX) transport around the UK • Implications of change in fuel type • Is nuclear power environmentally beneficial or environmentally harmful? Assess socio-economic impacts of option and, if appropriate, possible means of amelioration	Engage stakeholders, wider public and local community in an ongoing dialogue so that they understand the implications for them of this option and in order that the developer can understand their concerns Measure opinions locally and nationally and assess trends Establish current community attitudes to the existing Pu storage arrangements Identify what you need to do to promote this option (know the positive and the negative implications of this option) Explore implementation of transparent site selection process taking into account national , regional decision making processes and guidelines e.g. local engagement processes, site selection criteria, ***Notes***: • The importance of involving the community in strategic decisions (generic across all SAP's) • The value of involving the local community at sites (generic across all SAP's) • For this option, involvement in site selection is likely to be particularly important • Tension between national and local interests (generic across all SAPs)	Adapt implementation programme/strategy in light of monitoring Engage community in a process that helps them "buy into/understand" decisions and what the impact on their community will be Outcome of engagement process will be a factor in site selection Commence transparent site selection process engaging local communities at each of the candidate sites (EIA process provides one opportunity for engagement)	If trends negative, revisit explorations e.g. amelioration

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Costs, Funding & Contracts (R3)	Extend the existing collaborative agreement between BE/BNFL to establish the feasibility (commercial, economic, technical and political) of using Pu stockpile in new build reactors, including the explorations in this SAP (nb: as early as possible; does Govt. / LMA need to be brought in?) Separately, BNFL/LMA to consider whether there would be any preference for them to build/operate reactors in their own right	In the case where BE burns non BE Pu investigate all contractual issues (including the ownership issues relating to Pu and radioactive wastes) Explore potential contractual arrangements Establish the costs and funding for this MOX fuel option (spectrum is from profitable to subsidised) Establish the risks, operator responsibilities, liabilities in going in this direction	Decide on the preferred contractual basis Enter into negotiation to establish contract *(nb this may be lifetime contract including design construction and operation)* ***Note***: On the LMA model the whole operation would necessarily be contracted to one third party or another)	If can't establish the collaborative approach with BE, go for BNFL/LMA build or other options If can't agree contract revert to other options (build own reactor, immobilise it or get govt. subsidy because of UK policy) if the commercial assessment is bad, decide whether it is possible to do it on a subsidised basis for policy reasons

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Transport of new fuel (R3)	Confirm what existing modes and approved routes and assets are available to transport MOX to UK reactors Ensure stakeholders understand transport arrangements including safety, safeguards & security measures nb: link to societal issues	Review suitability of modes, routes and assets for transport of MOX to potential sites including safety, security and safeguard requirements and actions required to address any shortfall. If increased quantities of MOX are transported - are current arrangements including standards robust enough (to satisfy political acceptability) Monitor stakeholder and government attitudes to fuel transport and its risks Establish what measures eg exercises, are necessary to publicly demonstrate the adequacy of safety, safeguards and security risks management (joint fact finding?) Investigate availability /capacity of contingencies.	Decide modes, routes and assets that will be used. Commit to construction of any new assets required (mode or route change?) Take whatever actions are required following review	Increase safety, safeguards and security measures where practical In the event of a route being lost switch routes. In the event of a loss of mode: look to an alternative mode (could have impact on assets i.e. flasks, cranes, transport assets etc) • or store and / • or stop fuel production • or build new reactor at Sellafield (in long term situation) *nb Transport issues are minimised if selected site is Sellafield*.

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Transport of spent MOX fuel (R3)	Confirm what modes approved routes and assets are available to transport spent MOX from existing UK reactor sites sites Ensure stakeholders understand transport arrangements including safety security and safeguards measures. nb: link to societal issues	Review suitability of modes routes and assets for transport of spent AGR & LWR MOX including safety, security and safeguard requirements and actions required to address any shortfall Including to meet final dry waste form requirement Monitor stakeholder and government attitudes to spent fuel transport	Feed in the results of the review of spent MOX transport into waste management decision making on storage locations If transport is required, decide modes, routes and assets that will be used	If you can't transport, build sufficient storage capacity for lifetime arisings at reactor site(s) *nb Transport issues are minimised if selected site is Sellafield*.

Issues	Actions (now)	Explorations (now)	Deferred Decisions (later)	Contingency
Interim Pu storage (R3)	Confirm current storage capacity and required capacity	Determine if Pu storage will constrain the programme, having regard to when the option starts and its duration Assess whether existing storage is currently safe and structurally secure against risks and whether it will meet safety, security and safeguards standards for the required storage lifetime. Establish required actions to ensure that safety security and safeguards standards are met	Decide what actions might have to be taken to ensure continued safe, secure and safeguarded storage (This could include improving storage conditions)	Upgrade or build new stores (NB design studies are underway) Bring forward alternative options programmes if threat assessment warrants it.

FINAL DRAFT

PAPER BY THE SECURITY AND SAFEGUARDS SUB-GROUP OF THE PLUTONIUM WORKING GROUP

Annex 5:

PLUTONIUM MANAGEMENT OPTIONS, WITH SPECIFIC REFERENCE TO THE SPENT FUEL STANDARD'

At its meeting on 17 April, the PuWG broadly welcomed the report from the Sub-group on Security and Safeguards, and expressed the view that it was minded to forward the following recommendation to the Company Technical Executive:

That the company's assessment of the development requirements of immobilisation options focus on those options without an external radiation barrier. The assessment should, however, examine the feasibility and value of other potential 'intrinsic' security features.

Given the absence of some PuWG members from the meeting, it was decided to circulate this paper and recommendation prior to final endorsement at the next PuWG meeting on 30 April.

The following comments were also made in discussion at the PuWG meeting:

- Whilst noting the decision in the US not to proceed with immobilisation of surplus military plutonium, the conclusion in this paper regarding an external radiation barrier is based on the security and safeguard considerations for UK civil plutonium.
- It was noted that as a result of the US decision, certain immobilisation technologies will not mature as quickly as would have been the case.
- Further explanation needs to be provided on the way in which an external radiation barrier would complicate safeguards verification methods.
- The security and safeguards verification approach for all remaining immobilisation options needs to be carefully assessed.
- The technical development work for preferred immobilisation options is significantly different to that required for can-in-canister options.
- Further assessment of immobilisation options needs to include all waste management stages, including final disposal.

PAPER BY THE SECURITY AND SAFEGUARDS SUB-GROUP OF THE PLUTONIUM WORKING GROUP

Security and Safeguards Aspects of Plutonium Management Options, with specific reference to the Spent Fuel Standard

INTRODUCTION

This paper is in two parts:

Part A summarises the work of the sub-group on security and safeguards following a meeting in July 2000 and the subsequent paper[1] that was distributed to the Plutonium Working Group on the 6th September. This information is included as important background and because it formed the basis for subsequent discussion of the sub-group,

Part B summarises the issues raised at the sub-groups' second meeting on the 10th July 2001 that examined the implications and desirability of adding a radiation barrier to plutonium in order to increase its resistance to proliferation and theft.

[1] Sub-Group Working Paper of 6th September 2000.

WORKING PAPER BY THE SECURITY AND SAFEGUARDS SUB-GROUP OF THE PLUTONIUM WORKING GROUP

PART A - July/September 2000

The Sub-Group on Security and Safeguards has examined the implications associated with each of the main UK plutonium management options under study by the Plutonium Working Group (the paper of 6th September 2000 refers). That is to say:

1. Continue to store the UK owned stock of plutonium in high security vaults, under international safeguards, at Sellafield
2. Fabricate MOX fuel from the plutonium for burning in UK reactors
3. Immobilise the plutonium in a passively safe but radioactive matrix for interim storage, prior to eventual disposal.
4. Immobilise the plutonium in a passively safe ceramic form but without the addition of a self-protecting radiation barrier as in Option 3 above.

The analysis reached the following conclusions that are extracted from the 6th September 2000 working paper.

Option 1: Continued interim storage

It was agreed that the reality of the situation is that the interim storage of UK owned plutonium oxide is the only option available to the UK and BNFL in the short term (5 years+). In practical terms, plutonium oxide will continue to be stored at Sellafield for many years to come whatever option is chosen to manage plutonium in the future. For these reasons it is essential that the material is kept under stringent security arrangements and that all such plutonium is subject to Euratom and IAEA safeguards and verification arrangements. The existing arrangements were considered to be robust[2] and, given the UK's status as a Nuclear Weapons' State, the plutonium was not currently considered to be a domestic proliferation threat[3].

Options 2 and 3: Fabrication of MOX fuel and immobilisation with a radiation barrier

In order to assess the security and safeguards implications of these options the group found it helpful to consider material processing flow diagrams of these two options. These are depicted as Figure 1 in this paper.

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[2] The Sub-Group concluded in 2000 that the storage arrangements were robust and had the opportunity to visit a newly constructed plutonium store at Sellafield that was undergoing commissioning. Previously, the Royal Society had reviewed the storage arrangements for plutonium at Sellafield and reached the same conclusions. The WG noted, however, that these conclusions were drawn before the terrorist attacks in the US in September 2001

[3] The UK Ministry of Defence published its Strategic Defence Review (SDR) in 1998 that stated that it currently has a surplus of plutonium and intended to bring the surplus amounts into safeguards at Sellafield (note - this has been largely accomplished and will be complete in 2002). Accordingly, there is no political or strategic basis for removing plutonium from safeguards for military use and the UK Government has given the assurance that all transfers from safeguards will be published to aid with the transparency of this National policy. All spent fuel from the Chapelcross reactors (the only UK reactors not under safeguards) is brought under safeguards on receipt at Sellafield prior to it being reprocessed. The Calder Hall reactors were brought into safeguards in 1996.

WORKING PAPER BY THE SECURITY AND SAFEGUARDS SUB-GROUP OF THE PLUTONIUM WORKING GROUP

In each case, the management options start with the stored plutonium, as described above, and each will require many years to elapse before the stock is reduced to single tonne quantities of plutonium remaining in store. In this form, the un-irradiated plutonium is categorised in security terms as Category 1 material (i.e. direct use material) and requires stringent protection and verification.

Subsequently, both options require the plutonium oxide to be processed, first in an un-irradiated form, and then in a way which produces a self-protecting radiation barrier.

For MOX process plants, fuel fabrication involves a variety of automated process stages to manufacture ceramic pellets, fuel pins and assemblies. The initial process stages rely on nuclear materials accountancy and control to give the necessary safeguards' assurance but once the MOX is in the form of fuel pins and assemblies, the safeguards' regime is considerably simplified and based mainly on item accountancy[4] [5].
Category 1 security measures must be applied throughout the process because the plutonium remains un-irradiated and will be in quantities above the 2kg threshold.

The immobilisation route, whether "low spec MOX" or some form of ceramic puck production, will also require a degree of plutonium processing in the un-irradiated state. Full processing details are not established at this time but it was agreed that differences between the MOX and immobilisation routes for UK owned civil plutonium are unlikely to be significant in safeguards and security terms. Both will require the processing plants to have category 1 security protection and both will need comprehensive safeguards arrangements involving facility design information, accountancy and control, containment and surveillance measures and timely verification.

The second stage of the MOX and immobilisation routes is to generate a radiation barrier to reduce the accessibility of the plutonium.

For MOX, this is produced as a result of normal reactor operations and the radioactive isotopes form an integral part of the fuel. If the reactors are at Sellafield, the transport requirements between the MOX plant and the reactors will be considerably simpler than for off-site movements. Nevertheless, the fuel will need to remain under Category 1 security arrangements until after it is loaded into the reactor. Subsequently, the security can be reduced in line with international recommendations because of the protection afforded by the reactor and the increasing radioactivity of the fuel. Safeguards arrangements for MOX fuel prior to and after loading are applied routinely in Europe[6] [7].

The issues are comparable for the facility that would need to be constructed in order to combine the un-irradiated low-spec MOX or plutonium pucks with highly radioactive material to create a radiation barrier. Just as nuclear reactor fuel ponds hold fresh MOX fuel

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[4] Howsley et al (1997), "Safeguarding of Large Scale Reprocessing and MOX Plants", IAEA-SM-346/111
[5] Kaiser et al (1998) Effective Safeguards by Design in the Commercial MOX Facility at Sellafield.
[6] Burrows et al (1996), "The Safeguarding of MOX Fuel Facilities in Europe: A Reality", INMM Annual Meeting, Naples.
[7] Report from the Commission to the European Parliament and the Council – Operation of the Euratom Safeguards Office 1999-2000, COM(2001) 436 final.

prior to loading, the immobilisation plant will need to have a store to temporarily house plutonium pucks etc prior to the addition of a radioactive barrier. It will therefore need Category 1 security protection and full safeguards. Subsequently, as the pucks etc are processed and a highly radioactive barrier is added (such as the "can-in canister" option), the security and safeguards regimes can be reduced in line with existing international standards.

The final, irradiated materials from both routes also have comparable security and safeguards requirements. Both are likely to need significant security protection although this will depend on a number of technical features such as the radiation field and plutonium content of the "product". Initial USDOE plans to produce vitrified containers with about 10% w/w plutonium would lead to the production of canisters with a considerably higher (3x) concentration of plutonium than that in spent MOX fuel. Both "products" will require continued management oversight during interim storage, pending final decisions on long-term management. Both "products" have protective radiation fields that decay with time, rendering the plutonium more accessible (in theory at least). Both "products" would require expensive engineering facilities to extract the plutonium. Although the risk of undeclared diversion from either of the "products" is minimal in a UK context, it cannot be ruled out completely.

Option 4: Immobilisation of plutonium in a ceramic form without a radiation barrier

The Sub-group also examined the security, safeguards and proliferation issues associated with immobilising plutonium in a ceramic form without the addition of a self-protecting radiation barrier. Instead, the immobilised plutonium could be made less accessible by storing it in close proximity to radioactive materials (such as vitrified high level waste) or by making its theft less likely by storing it in heavy security containers that would be difficult to move.

At the time of this work, there was a difference of opinion within the Sub Group on the adequacy of the security arrangements if a radiation barrier was not added to the immobilised plutonium. It was for this reason that the Sub Group was asked to reconvene to discuss the issue in more detail.

WORKING PAPER BY THE SECURITY AND SAFEGUARDS SUB-GROUP OF THE PLUTONIUM WORKING GROUP

PART B - JULY 2001

Subsequent studies by the sub-group on security and safeguards

The Sub Group met for a second time on the 10 July 2001 to further examine the issues and to give thought to whether the addition of a radiation barrier and the attainment of the "Spent Fuel Standard" for civil plutonium stocks would serve any useful purpose.

The "Spent Fuel Standard" arose out of studies in the US to examine the proliferation resistance of different types of plutonium-bearing materials that could be produced from surplus military plutonium, principally either spent MOX fuel or immobilised plutonium protected by a radiation barrier. In both cases, the level of radiation is similar to that found in spent LWR fuel and as such affords the plutonium equivalent protection to that of spent LWR fuel, which is deemed to be adequately protected and safeguardable.

The UK Government, in common with all other States, does not recognise the Spent Fuel Standard as an international standard for civil nuclear materials because it has no internationally agreed definition.

Its principle purpose was to establish a rough definition to guide bilateral disarmament discussions between the US and Russia and to meet US concerns that the Russians might seek to store their surplus plutonium in forms that could be easily recovered and returned to military service. As it is, the Russians do not intend to immobilise any military plutonium, making it all into MOX fuel, so the Spent Fuel Standard for immobilised plutonium in Russia is of no immediate relevance. Furthermore, US plans to immobilise its military plutonium by means of the "can-in-canister" process have been delayed and some believe that the programme could be cancelled (NB - the US President cancelled the immobilisation programme later in 2001[8]). Irrespective of this, it is important to recognise that the verification arrangements for immobilised military plutonium (i.e. under Article VI of the Non-Proliferation Treaty[9], will not be conducted to the same standards that apply to civil nuclear material (i.e. under Article 3 of the NPT). Consequently the verification arrangements agreed between the US and Russia for ex-military material will be unacceptable in a civil nuclear context. This is an important point because there is a legal obligation for the declared UK civil plutonium stockpile to be maintained under international safeguards.

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[8] In a report requested by Congress last year and just released ("Report to Congress: Disposition of surplus defense plutonium at Savannah River Site", USDOE, February 2002), DOE presented results of its review of the US Excess Weapons Plutonium Disposition programme, in which it re-examined various potential options for Plutonium Disposition. From the eleven options considered, DOE selected the option that utilizes MOX and eliminates the Plutonium Immobilisation program altogether. Various factors were considered in the review of each option, including costs, schedule, technology maturity, non-proliferation objectives, international support, and US/Russian obligations. This review is a subset of the broader review undertaken last year by the DOE and the National Security Council, in which a thorough examination of the overall merits of the US and Russian Plutonium Disposition programs was undertaken. While the MOX option is now favoured for both the US and the Russian programs, further discussions between the US and Russia (and indeed the G8) will be required to identify which MOX options might be possible in Russia to accelerate that program and to best leverage government contributions.

[9] IAEA 45th General Conference Press Release 2001/19 - "IAEA Verification of Weapon-Origin Fissile Material in the Russian Federation and the United States".

Accordingly, the main question for the Sub Group to consider was whether the addition of a radiation barrier to immobilised plutonium has any beneficial effect on the security and safeguards regime for civil, safeguarded material.

Issues discussed

The system of International Safeguards has a central goal of verifying that civil material is not diverted from peaceful end-use commitments and it uses methods of re-verification to achieve this goal. This requires Inspectors to have access to the nuclear materials to re-measure stocks and flows and to protect their continuity of knowledge through containment and surveillance. In the case of the THORP store for example, Euratom (and the IAEA) reserve the legal right to re-verify (re-measure) every can of plutonium in store if they, at any time, believed that continuity of knowledge had been compromised. Under normal arrangements, the Inspectors rely on a complex set of sealing devices, coupled to their CCTV cameras in the store to provide the necessary assurances, as well as 100% verification of all plutonium entering and leaving the store. They also randomly select a number of cans for re-measurement at the annual inventory.

Proposals to add a radiation barrier to the stored plutonium would not make re-verification easy and considerable thought would have to given to how this could be achieved. Similarly, the standard technique used to measure the plutonium content of plutonium oxide is by neutron coincidence counting and gamma spectroscopy. These methods have become highly refined and routine over many years and result in high precision measurements. The intentional inclusion of neutron poisons in immobilised plutonium (to control long-term criticality in a repository) would generate significant measurement difficulties that would require consultation with the Safeguards Inspectorates to see if revised techniques could be developed. This would not be a trivial task.

From a security perspective, all nuclear materials can be successfully guarded but the costs of guarding direct-use materials are usually higher than other nuclear materials such as spent fuel. In theory, converting plutonium into forms with a radiation barrier would reduce the costs of security, but in practice the security needs for a site such as Sellafield are largely determined by overall site requirements and the presence or absence of any one material type or facility is largely irrelevant.

The security threats that must be defended against include sabotage and theft and the material form and storage arrangements have a bearing on the relative risks and that is why security arrangements are tailored to suit the risk. In this respect, the presence of a radiation barrier around immobilised plutonium does not seem to be of immediate or obvious benefit. On the one hand it might prevent or make more difficult the theft of the material and gaining access to it for purposes of sabotage (clearly this depends markedly on the scenario and if the storage container is shielded). Conversely, the successful sabotage (i.e. dispersal) of highly radioactive waste in addition to plutonium is likely to cause additional difficulties for subsequent decontamination.

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In principle, there could be benefits in firstly dispersing the plutonium in a matrix that makes recovery difficult and secondly if the material is stored in heavy containers or robust stores, as long as the safeguards regime is acceptable to International Regulators. "Intrinsic security" would be enhanced because the risk of theft would decrease under some scenarios, the plutonium might be more difficult to separate and the matrix/container/store would provide substantial resistance to ballistic forces, so minimising the risk of dispersal. However, regulations require security measures, including institutional arrangements, to be tailored to the type and form of nuclear material, with the aim of providing comparable security whatever the material. On this basis the only justification for including a radiation barrier for immobilised plutonium would be in the political context of international, bilateral assurances relating to nuclear weapons' disarmament. Indeed, this is the only context in which the Spent Fuel Standard has any meaningful definition.

Nonetheless, given the PuWG's view that an alternative approach to the management of plutonium stocks needs to be developed, there would be merit in examining further if other "intrinsic security" arrangements should apply. These might include but not be limited to; difficulty of separation of plutonium from its matrix, difficulty of extracting plutonium from its storage container and difficulty of moving the storage container.

CONCLUSIONS

- There is no internationally agreed definition for the spent fuel standard and it only has relevance in the context of international, bilateral nuclear weapons disarmament initiatives,
- Nuclear materials recovered from military programmes are not necessarily safeguarded and verified to the same standards as civil nuclear materials,
- The vast majority of the UK plutonium stockpile is civil in origin and there are legal obligations for the material to remain subject to proper safeguards verification,
- The addition of a radiation barrier would complicate the existing safeguards methods for verifying plutonium oxide or fresh MOX and successful verification would require novel approaches that do not currently exist,
- The addition of a radiation barrier is of questionable benefit to the overall security of the plutonium. It may increase the difficulty of successful theft by increasing the intrinsic security of the stored plutonium but there are other ways of achieving adequate security that do not require the vast expense and technological challenge of an artificial radiation barrier. Nonetheless, given the PuWG's view that an alternative approach to the management of plutonium stocks needs to be developed, there would be merit in examining further if other "intrinsic security" arrangements should apply.

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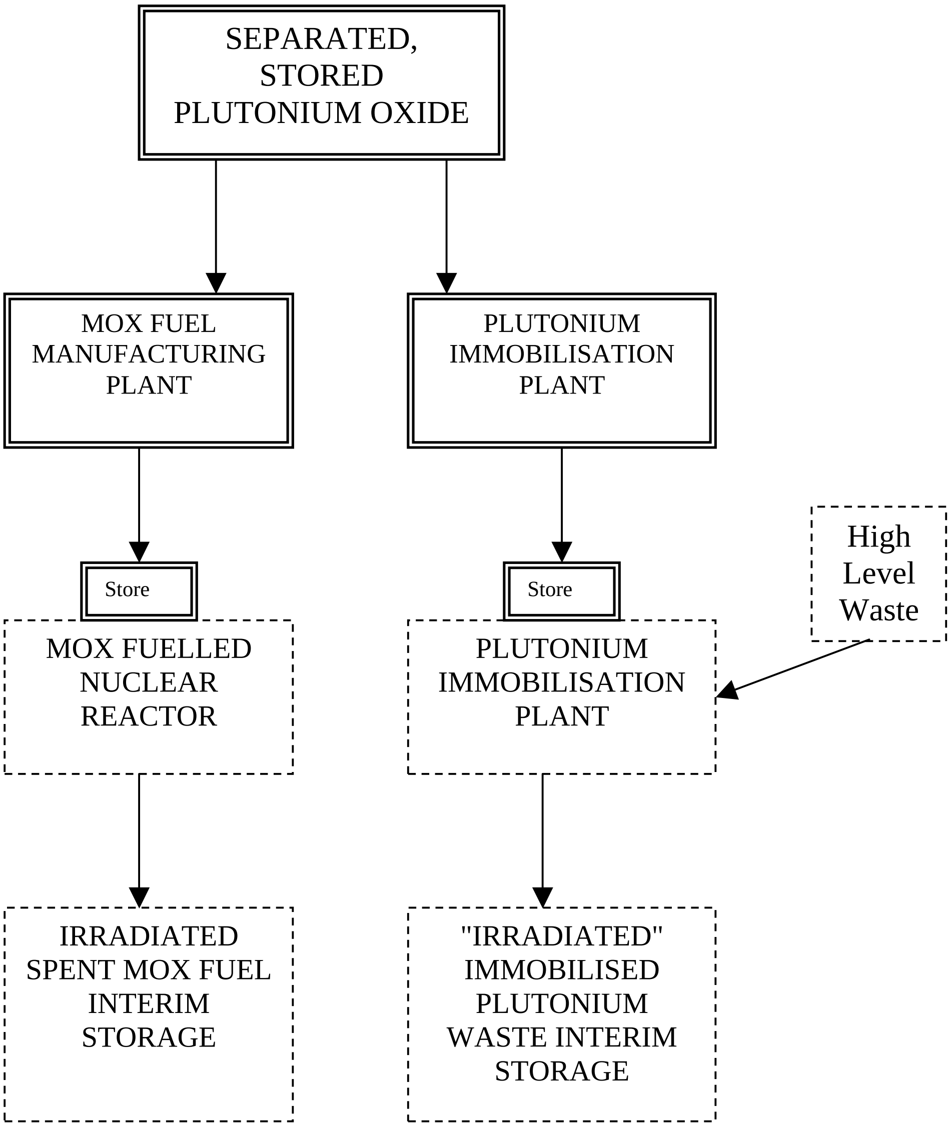
Figure 1

Process flow diagrams for MOX fuel and immobilisation options



KEY:
Facilities bounded by **double** lines represent those processing or storing unirradiated plutonium, requiring Category 1 security arrangements

Facilities bounded by **dashed** lines represent those processing irradiated plutonium, requiring Category 2 (or lower) security arrangements

Verification issues for immobilised plutonium with an external radiation barrier

This note is provided to the Plutonium Working Group to help explain the theoretical and practical difficulties that would be faced in attempting to verify the plutonium content of immobilised plutonium where techniques such as the Can-in Canister are used. The pictures overleaf depict the plutonium pucks that were envisaged by the USDOE and the packing arrangements for the cans and canister. The overall size of the canister would have been about 1m diameter and 3m in height.

Because the plutonium to be immobilised originated in the US weapons programme there would have been no obligation to apply international safeguards verification measures. The US and Russia would have come to an arrangement with the IAEA that provided sufficient assurance that the plutonium was in a form that prevented the easy return of the plutonium to the weapons' programme.

By contrast, civil origin plutonium immobilised in this way would need to be verified according to international safeguards criteria. This would require the safeguards authorities to verify the plutonium content of pucks, establish methods to prove that all pucks are loaded into cans and maintain full continuity of knowledge after the cans were loaded into the canisters, both before and after the highly radioactive glass is poured around the cans. There would also have to be a way of verifying that canisters in store still contained cans of immobilised plutonium in the event that it became necessary to check the inventory of the canisters.

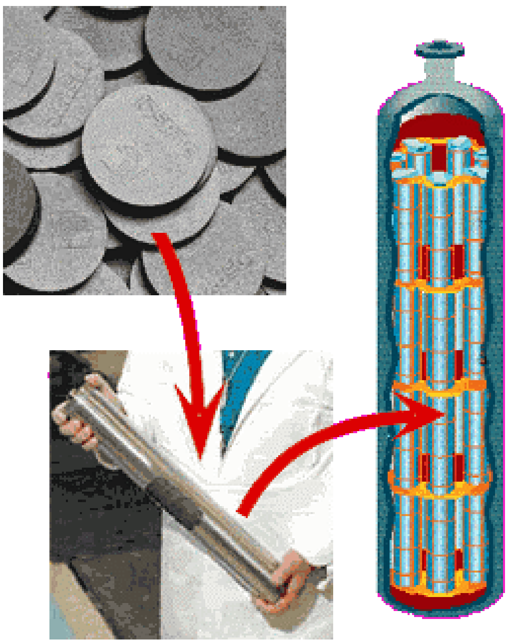
The usual methods of verifying plutonium rely on non-destructive analysis, by using instruments that measure the gamma signature and neutron dose rates. The methods for plutonium oxide and MOX are in routine operation and yield high quality results. The likely problem for can-in-canister methods is that the gamma and neutron dose rate of very high level waste (VHLW) is very much higher than that of plutonium; the gamma dose rate would be about 1 million times higher than for plutonium, and the neutron flux about 100 times higher. The glass would also shield the plutonium neutron signal and make it extremely difficult to detect against the very high signal from the VHLW. Furthermore, the analysis of neutron signals would be much more difficult to use to prove the presence of plutonium because the energies of the neutrons from plutonium and VHLW are not as distinct as those from gamma rays.

These theoretical problems would be compounded by the practical difficulties associated with gaining access to the highly radio-active canisters to make any sort of measurements at all.

Can-in-Canister Concept for Immobilised Plutonium

(a) Puck of Immobilised Plutonium

(b) Pucks of Plutonium packed in cans and arranged spatially in Canister prior to pour of highly radioactive glass to fill spaces between cans.



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ANNEX 6: EXCHANGE OF QUESTIONS AND ANSWERS WITH OCNS

FIRST EXCHANGE (July 2002)	
SSSG Questions	***OCNS Answers***
1 What steps were taken after Sept 11 to review the security arrangements at BNFL sites and for the transport of MOX fuel?	We immediately asked NII to identify the potential consequences of a similar incident at each licensed site, in particular asking them to identify the sequences of consequential processes that could lead to an off-site release or immediate fatalities. Focused reviews of security were then carried out on a site specific basis.
2 What processes are used to identify plausible security threats?	We are in constant dialogue with the intelligence community and police and in regular contact with other organizations (government and commercial) with security expertise. We liaise regularly with our opposite numbers in the US and in Europe
3 What processes are used to decide which threat scenarios to plan against?	The Design Basis Threat is a statement of the capability that any civil nuclear facility anywhere in the country has to be able to defend against. It is determined by what we know, or can reasonably expect, the maximum capability of a hostile group or individual to be. Anything below that defined capability is plausible
4 How have these processes changed following Sept 11?	The *process* hasn't changed: it has always been intended to identify as best we can the greatest capability we expect the facilities to deal with.
5 How has the definition of plausible threats and potential consequences changed as a result of Sept 11?	The potential consequences, however small, of theft or sabotage have always been taken extremely seriously. This has not changed. We are not prepared to discuss threat assessments.
6 How has the design basis threat for (a) the Sellafield site and (b) MOX transport changed as a result of Sept 11?	We are not prepared to discuss threat assessments or specific security measures. It is the nature of deliberate threats – and of terrorism in particular – to exploit knowledge to their advantage. For the most part, they have the advantage of surprise: it is helpful if the defenders can retain some as well.
7 What types of additional security measures are being taken as a result?	We are not prepared to discuss threat assessments or specific security measures. It is the nature of deliberate threats – and of terrorism in particular – to exploit knowledge to their advantage. For the most part, they have the advantage of surprise: it is helpful if the defenders can retain some as well.
8 How are decisions taken about what constitutes an acceptable level of security planning/measures?	Security measures have to be capable of defeating the Design Basis Threat.
9 What criteria are used to evaluate security arrangements?	Security measures have to be capable of defeating the Design Basis Threat.

SSSG Questions	***OCNS Answers***
10 How are issues of (a) cost and (b) political judgement taken into account in reaching decisions about acceptable levels of security measures?	We are open to representations about the cost of specific measures but require any proposed cheaper alternatives to be equally effective.
11 In what circumstances might political judgements over-rule the judgement of security experts?	OCNS is operationally independent. The Draft Regulations include an appeals process for the operators.
12 What factors explain the different responses - in terms of military defence measures around Sellafield and La Hague - of UK and French authorities to Sept 11?	It would be inappropriate to comment directly on the security decisions of another state. Each state applies the measures that most suit its own circumstances and security arrangements. You will have noted, however, that the military measures around La Hague were temporary.
13 How are 'outsider' commentaries/critiques of security arrangements in (A) UK and (B) abroad monitored?	We take a wide range of publications reflecting all sectors of opinion as well as having our attention drawn by others to critiques they believe we should no about.
14 In what ways have these commentaries/critiques impacted on reviews of those arrangements?	Without being specific, we react to these commentaries as we would to any other document. That is, do they have something relevant, well-founded, and objective to say about consequences, vulnerabilities, threats and countermeasures. It is in nobody's interests for any of us to behave as if we know it all.
15 How will BNFL/OCNS (a) assess and (b) respond to the STOA analysis of the effects of a terrorist attack on facilities at Sellafield?	Ditto
16 What are the main areas of disagreement with the STOA analysis of the effects of a terrorist attack on facilities at Sellafield?	Again without going into specifics, it is important to distinguish between a terrorist attack and a successful terrorist attack. Given that any terrorist attack on a nuclear site is undesirable - i.e. even if we thought it would have zero impact – the security objectives (deterrence, detection, delay, response) are set so that nothing untoward should happen. In the event of security being overcome, the appropriate mitigation/contingency measures come into play.
17 What process has OCNS used to review the security of (a) liquid HLW tanks and (b) Pu stores against terrorist attack?	See Q1
18 What studies have been undertaken, or are underway, to assess the impact forces that key plant on the Sellafield site can withstand?	This is under active consideration by NII, OCNS and others but is a more complex issue than the question seems to suggest. A large impact on some key plant may not give rise to an off-site hazard. Where plant might seem susceptible, re-enforcement could prevent the run off of aviation fuel: at some plant, fire is likely to be the larger hazard.

SSSG Questions	***OCNS Answers***
19 What criteria will be used to decide whether, and if so what, physical/structural improvements will be undertaken as a result of these studies?	What, if anything, will be done will need to take account of the likelihood of on-site/off-site hazards, alternative means of prevention and the balance of risks (see Q18)
20 How is the level and type of armed escort for MOX sea transport decided?	We are not prepared to discuss threat assessments or specific security measures.
21 How are the routes for sea shipment of MOX decided? What are the criteria for choosing between possible routes?	We are not prepared to discuss threat assessments or specific security measures.
22 Why are military escort vessels no longer used for sea transport of MOX?	We are not prepared to discuss threat assessments or specific security measures.
23 In the event of a terrorist attack on a ship carrying MOX fuel, what measures are available to deal with fire and sinking?	Answer at Q16 applies.
24 What steps would be taken to recover flasks of MOX fuel which had sunk in deep water?	Not a question of OCNS, but contingency plans are in place
25 Who pays the costs of the security measures associated with MOX transport?	The Operators
26 If new reactors are to be built in the UK, what steps would be taken to enable them to withstand the type of aircraft impact on Sept 11?	We are not prepared to discuss specific security measures.
27 More specifically, what design modifications might be necessary to the AP1000?	We are not prepared to discuss specific security measures.
28 What assessments have BNFL or OCNS undertaken of the security arrangements needed to enable MOX use at existing UK reactors (particularly Sizewell B), covering (a) transport to the reactor site and (b) storage and use at the reactor site?	All use, storage, and transport of any nuclear material is conditional on the Licensee obtaining prior approval based on a detailed security plan. Security arrangements are subject to inspection.
29 What steps have been taken to review such assessments following Sept 11?	See Q1. In practice, security plans are subject to frequent review and updating.
30 What communications has OCNS had with its United States counterparts in respect of the additional measures that have been taken in the US to protect (a) nuclear facilities and (b) nuclear materials in transit?	We have corresponded and visited our opposite numbers in the US and in Europe

SSSG Questions	***OCNS Answers***
31 What communications OCNS has had with the experts within (a) The European Commission (b) the EC Joint Research Centres and (c) EURATOM in respect of evaluations made (1) before and (2) since Sept 11 on the adequacy of security provisions in place to protect (i) nuclear facilities and (ii) nuclear material in transit from and into the EU?	These bodies have no locus, accountability, or responsibility for security.
32 What non governmental/academic bodies have been consulted on security issues post Sept.11	OCNS consults with experts in a variety of relevant fields but we are not prepared to go into details.
33 What input OCNS has had in the drafting of ministerial parliamentary answers?	OCNS is consulted by other officials in DTI to ensure the replies are as informative and accurate as they can be subject to the need to protect sensitive intelligence and detailed security measures.
34 When in March was the OCNS first annual report delivered to the Energy minister; and when will it be published	The Report has been published, together with an explanation for the delay.
35 What specific input did OCNS have in reviewing for ministers the BNFL/Environment Agency case for operation of SMP following Sept.11?	See Q1
36 How many breaches of air avoidance zones around (a) civil and (b) military nuclear facilities in the UK have occurred in each year since 1992? And can OCNS elaborate on the details?	Not for OCNS to answer. NB Air exclusion is for safety not security reasons.
37 What input OCNS had in the drafting of the Air Navigation (Restriction of Flying) (Nuclear Installations) Regulations 2001, which came into force on 11 May 2001?	OCNS was consulted but did not see this as a security issue.
38 With which counterpart Agencies or Offices does OCNS liaise in the EU member states?	OCNS consults widely with fellow security regulators (or their designated experts) across Europe and beyond but especially France, Germany, Holland, Sweden
39 Does OCNS have access to any expertise in the construction of nuclear explosive devices from ‘reactor’ or ‘fuel ‘ grade plutonium?	OCNS is, obviously, aware that there is a debate in some quarters on this issue but does not need to make a judgment because, in practice, OCNS treats all types of Pu as the same. That is, it must be secured whatever its origin or supposed grade.

SSSG Questions	***OCNS Answers***
40 Whether the OCNS provided any support to the United Kingdom legal case Vs the Irish Republic at the International Tribunal for the Law of the Sea, held in Hamburg on 19-20 November 2001?	
41 Whether the OCNS was consulted by the DTI and/or the office of the secretary of state in preparation of the 28 November 2001 Parliamentary statement made on the proposed creation of a Liabilities Management Authority covering nuclear activities; and what consideration has been given by OCNS to the implications of ministers declaring plutonium as a waste under LMA management, as is foreshadowed by the Radioactive Waste White Paper?	OCNS has emphasized that all bodies licensed to use, store, or transport nuclear materials are subject to the same security regulations. It is the nature, physical state and quantity of nuclear material that determines the rigour with which it must be secured: whether or not it is designated waste is not relevant to its security
42 Has OCNS either offered of been asked to tender advice to the Foreign Office in respect of the security protection measures in place to cover MOX fuel in transit to (a) continental Europe and (b) Japan by sea?	OCNS is the designated UK competent authority for the security of nuclear materials in transit. We will inform other government departments as necessary on the decisions we have made.
43 Has any meeting been sought by the OCNS counterpart in Ireland in respect of Sellafield security?	A meeting has been sought and has been agreed to
44 Has any OCNS assessment been made of how long it would take a commercial passenger aircraft flying at 2,200 feet above sea level two nautical miles from Sellafield to reach Sellafield?	Yes but we are not prepared to discuss threat assessments or specific security measures.
45 What/how many discussions OCNS has had with the NII chief inspector in respect of security arrangements for the (i) high level waste storage tanks and (ii) the plutonium storage bunkers at Sellafield?	Security is a matter for OCNS alone. However, there are overlapping interests, not least in contingency arrangements. OCNS and NII are in frequent discussions on these and other matters.
46 What assessment OCNS has made of the availability in the public domain of detailed site plans of buildings at Sellafield?	OCNS would be interested in the views of the group on this subject. We are looking at ways of limiting the availability of some types of information but this needs to be balanced by the legitimate needs of the taxpayer, local residents and other authorities, especially the emergency service.

SSSG Questions	***OCNS Answers***
47 When OCNS most recently reviewed NUREG-0800 in respect of its applicability to the United Kingdom?	
SECOND EXCHANGE (September 2002)	
48 Did the focused reviews of security result in any enhancements in arrangements at specific sites? If so, which sites?	The reviews resulted in enhancements at all sites to some degree. It would be inappropriate to provide details but we can confirm that at both Sellafield and Dounreay some additional internal security measures were introduced to further protect specific processes and facilities.
49 As the September 11 attacks prompted a significant reassessment of the threat posed by Islamic terrorist groups, presumably the DBT become more onerous as a result? If so, is the revised DBT leading to significant changes in the design, implementation and management of security measures and systems arrangements of the civil nuclear companies?	The DBT is not for public discussion for the understandable reasons given previously but we can confirm that it was reviewed following the September 11 attacks. Security arrangements in the UK are under constant review by both the operators such as BNFL and by the Government with the aim of identifying any necessary improvements. The improvements include advances in technology and enhanced management and communications systems.
50 Are there any public domain versions of OCNS security standards, criteria and guidance material? Are there any public domain versions of IAEA guidance in this area?	Security systems, and many individual security measures (for example, combination locks, intruder detection systems, CCTV, firewalls for IT systems etc), are designed to resist attack even if the attacker knows that they are in place. Nevertheless, it could assist a potential aggressor to know what measures are, or are likely to be, in place in any particular location and therefore OCNS has no plans to publish the standards and guidance it provides to the industry. New security regulations will be in the public domain in due course. IAEA publishes a number of documents (see their web-site re internet access to some of these and for important caveats on the status of different types of document). Of particular relevance to the question is IAEA-TECDOC-1276, Handbook on the physical protection of nuclear materials and facilities, Vienna 2002, ISSN 1011-4289 but it should be noted that this, as with all other TECDOCs, has no official status.

SSSG Questions	***OCNS Answers***
51 How does a criteria-based approach differ to that previously adopted?	A criteria-based approach requires site operators to show in their plans and in practice how they counter the threats as described in the DBT. A compliance-based approach requires site operators to show that their plans and their practices incorporate the security measures required by the Regulator (usually in the form of Manuals). A criteria-based approach promises to provide a dynamic response to changing threats. A compliance-based approach tends to put the emphasis on getting the right boxes ticked: this has merit - there is a need for a formal acknowledgment that planned measures are in place - but it does not ask whether the measures are appropriate to the current threat. The criteria-based approach puts the responsibility and accountability on those who control the budget are best placed to deliver appropriate security; and it increases the effectiveness of the Regulator. In practice, because we make use only of expert inspectors, OCNS has always used both approaches but we wish to formalise how criteria-based assessments are recorded, monitored and inspected.
52 In the light of the STOA analysis, have the relevant security/mitigation/contingency arrangements been reviewed and found to be adequate? Have any improvements to arrangements been made as a result?	We have nothing to add to the earlier reply (answer 15) in respect of STOA.
53 Will there be any public domain versions of the findings of the studies underway by the NII, OCNS and others on the impact forces that key plant on the Sellafield site can withstand?	A decision to make information available will need to take account of any public interest benefits and the disclosure of information that could assist a potential aggressor. That decision cannot be made until findings are available.
54 Have there been any discussions between OCNS and civil nuclear companies about the security measures that might be required for new nuclear power stations? Is OCNS undertaking any review of the security measures that might be needed for new nuclear power stations in the UK?	There have been no discussions about the security measures required for new nuclear power stations. Should new power stations be considered, OCNS will wish to discuss with the operator/licensee the extent to which building and site design can incorporate security measures. However, this will not remove the statutory requirement for site operators to submit and have approved a specific security plan.

SSSG Questions	***OCNS Answers***
55 Para 45 of the OCNS report to the Secretary of State refers to an expert group which is addressing the balance between confidentiality and transparency. When do you expect the expert group to report? Will a public domain version of the group's findings be made available?	The aim is to produce transparent reasons for the protection of certain categories of information and, if possible, do so in a way that does not itself need protection. The challenges are to word the reasons so that they do not provide leads for potential aggressors and to word the guidance so that it is usable by a wide range of organisations. The Group hopes to finish this stage of its work in November. The Group has met on a number of occasions during 2002 and hopes to complete its work this year. The conclusions of the work will be communicated to operators to guide them in assessing whether nuclear related information should be protected. It may be possible to publish some information about these developments and we will, if prudent to do so.

Annex 7: Exchange of Questions and Answers with Nirex

1. Does the Company have a view on how Pu should be stored over long periods?

Nirex have considered the question raised in the DEFRA and Devolved Administrations Consultation paper on the policy to be adopted for the long-term waste management of UK separated plutonium, including whether some of the stock should be considered as waste. A Technical Note [Ref 1] has been produced by Nirex as a discussion document to provide information on the implications of declaring the UK separated stock of plutonium as waste.

This Technical Note does not make any recommendations on whether plutonium should be declared a waste. It does, however, highlight that there will need to be a comprehensive and integrated strategy for all materials (including plutonium), in order that:

- public concerns can be addressed at an early stage;
- late/additions/changes to the range of wastes included in the developing strategy are minimised;
- any future programme will not be delayed by revisions to decision-making.

2. How might interim storage conditions for spent MOX fuel and immobilised plutonium wasteforms impact on disposability?

The disposability of spent MOX fuel / immobilised plutonium might be affected during interim storage if the conditions of storage allow significant and/or irrepairable degradation of the fuel/wasteform/container where the performance/integrity of these components affects the performance of the disposal system.

a) MOX Fuel

Internationally, there is up to ~40 years experience of interim storage of spent oxide fuel following discharge from reactor. Based on this experience, options[1] for the interim storage of MOX fuel include:

1) pond storage:

2) dry storage:

3) cask storage, which may be wet or dry.

Interim storage takes advantage of the continued corrosion resistance and integrity of the fuel cladding (principally zirconium alloys, in some cases stainless steel) which contains the oxide fuel pellets and fission products. Depending on the option chosen, additional barriers may be used, for example to reduce radiation levels or to exclude oxygen (in air, in case the fuel cladding contains undetected defects).

The disposability of spent MOX fuel might be affected if interim storage conditions allow deleterious changes to the fuel pellets, cladding or outermost container (including lifting features) to progress too far. This might be by radiation effects, elevated temperatures or a corrosive environment. Fuel pellets and cladding are unlikely to be affected by radiation effects or elevated temperatures, since such conditions are experienced by the fuel at high power levels during approx. 5 years reactor operation. Any container should be designed to withstand anticipated radiation effects. The fuel cladding or an outer container could suffer degradation by corrosion, but this is capable of management by materials selection and design together with control of environmental conditions to prevent or limit degradation. This might include management of pond-water chemistry, or control of the atmosphere contacting the fuel cladding and/or containers (e.g. controlling the humidity and content of corrosive chemicals such as chloride).

[1] Internationally, all three options have been used for water reactor fuel (PWR, BWR, CANDU). In the UK, Option 1 is used, and Option 2 has been considered, for interim storage of gas reactor fuel (AGR).

b) Immobilised Pu Waste forms

There is little experience of the production and interim storage of immobilised plutonium waste forms. Several options for a waste form have been suggested, including:

- glass;
- ceramic;
- low spec MOX

The waste form would be associated with a container that may not necessarily be the disposal container. Interim storage of the packaged waste form could draw upon experience with spent fuel and vitrified HLW.

The impact that storage conditions could have on disposability is as above.

3. What issues arise if immobilised Pu or irradiated spent fuel are to be disposed of in a repository?

The key issues that arise when considering the disposal of immobilised plutonium or spent fuel in a repository include:

- Repository and transport design
- Transport, Operational and Post-closure Safety
- Public perception
- Programme of research and development and site selection
- Costs
- Criticality
- Safeguards and security

These are discussed in more detail in the discussion document attached [Ref 1 – attention drawn to reference 42 cited in that Technical Note].

4. What principles should be applied to ensure the disposability of Pu wasteforms?

From a technical perspective, the disposability of Pu wasteforms must address the immobilisation of particulate Pu (the most likely form of the Pu feed), the need for chemical containment of relatively long-lived radionuclides (Pu-239, Pu-240, Pu-242), the in-growth of Am-241 from Pu-241, and the prevention of criticality arising from the fissile nature of the key isotope, Pu-239.

A possible list of principles follows:

- chemical and physical stability (PuO_2 is chemically stable, but the fine powder form needs to be immobilised)
- compatibility with a disposal system
- management of the potential for a criticality (usually achieved by limiting the mass of material in a single package, although it may be possible to develop an encapsulant that will reliably outlive the half-life of Pu-239, thus allowing increased levels in a package)
- minimisation of human intervention and the need for active safety systems
- prevention of diversion for unauthorised uses (physical and radiological barriers are commonly suggested (or may be required as part of a safeguards regime), although they may need to be balanced against the possible recovery of the Pu from the waste as a resource)

- building stakeholder confidence.

These principles have been extracted from the following published documents:

- HM Government, Radioactive Waste Management - Final Conclusions (Cmnd 2919 (1995).
- Health and Safety Executive, Nuclear Safety Directorate, *Guidance for Inspectors on the Management of Radioactive Materials and Radioactive Waste on Nuclear Licensed Sites*. 13th January 2001.
- The Environment Agency, SEPA, Department of the Environment for Northern Ireland, *Disposal Facilities on Land for Low and Intermediate Level Radioactive Wastes: Guidance on Requirements for Authorisation.* (1997).
- United Kingdom Nirex Ltd. *The Packaging of Waste for Safe Storage, Transport, Handling and Disposal.* Nirex report N/006 (2000).

There are also potential ethical issues. In particular, there is the need to balance future recognition of the resource potential of Pu with the need to ensure it does not contribute to proliferation (via, for example, sub-national bodies, including terrorists). Such wastes will need to meet the requirements of a safeguards regime, and a facility will need to provide suitable physical protection for the waste.

5. What are the relative merits of glass and ceramic waste forms for Pu – including the loading of Pu that can be incorporated, and the relative resistance to leaching?

The relative merits of glass and ceramic waste forms for plutonium are discussed in a paper by Allison Macfarlane (Immobilization of Excess Weapon Plutonium: A Better Alternative to Glass, Science & Global Security, Volume 7, pp 271-309, 1998), see the summary table below.

Glass	Synroc
ability to accept impurities potential ability to withstand radiation damage	better proliferation resistance ability to accommodate at least twice as much U-238 and Pu-239 no effects from 2nd glass pouring chemical durability over time production safety

Preliminary Nirex studies have investigated the implications of deep disposal of plutonium in cement, glass and as spent MOX fuel [Ref 1]. Future studies will investigate the issues associated with deep disposal of other plutonium waste forms.

6. What are your views on assuring security of Pu in waste forms?

See response to question 7.

7. What comments do you have on the PuWG's papers on security?

There have been numerous discussions, internationally, on the best means for preventing plutonium proliferation including the application of enhanced safeguards measures (essentially 'passive' measures) and its 'dilution' in other materials, including radioactive 'waste'. There is a balance to be struck here insofar as the two approaches are not necessarily complementary. For example, it is likely that the production of a radioactive waste package containing dispersed plutonium will prevent accurate and reproducible measurement/determination of the Pu content employing current techniques. Hence, there is an argument that if the inspecting authority (IAEA or Euratom) is unable to measure the Pu content with sufficient accuracy, then the proliferation potential is actually increased. The efficacy of achieving the so-called 'spent fuel standard' can therefore be called into question.

The measures required for the physical protection of plutonium in storage are well defined and particularly stringent. In general, these security measures are complementary to safeguards measures, particularly where the former include regular inspection and controlled access. It is possible that the safeguards authorities would also prefer higher security for plutonium with relatively well controlled access for measurement and inspection rather than to promote a situation with a reduced level of security and more challenging measurement and inspection requirements. There is a need to examine other 'intrinsic security' measures and consider their implications on the safeguards approach for the facility.

Nirex views on safeguards are also discussed in the attached report "Technical Note: Implications of Declaring UK Separated Stocks of Plutonium as Waste" [Ref 1].

8. If spent MOX fuel or immobilised plutonium were to be co-disposed either in a repository for the UK's ILW inventory or in a repository for the UK's HLW inventory, are there any significant implications for the design, operational or post-closure safety cases for including this waste in the repository? - Would Nirex please include comment on the logistical implications of emplacing the additional volume of waste over the repository lifetime and whether this would require design changes which would lead to significantly increased costs.

The issues associated with disposal of separated plutonium either in a repository for the UK's ILW inventory or in a repository for the UK's HLW inventory are discussed in Ref 1.

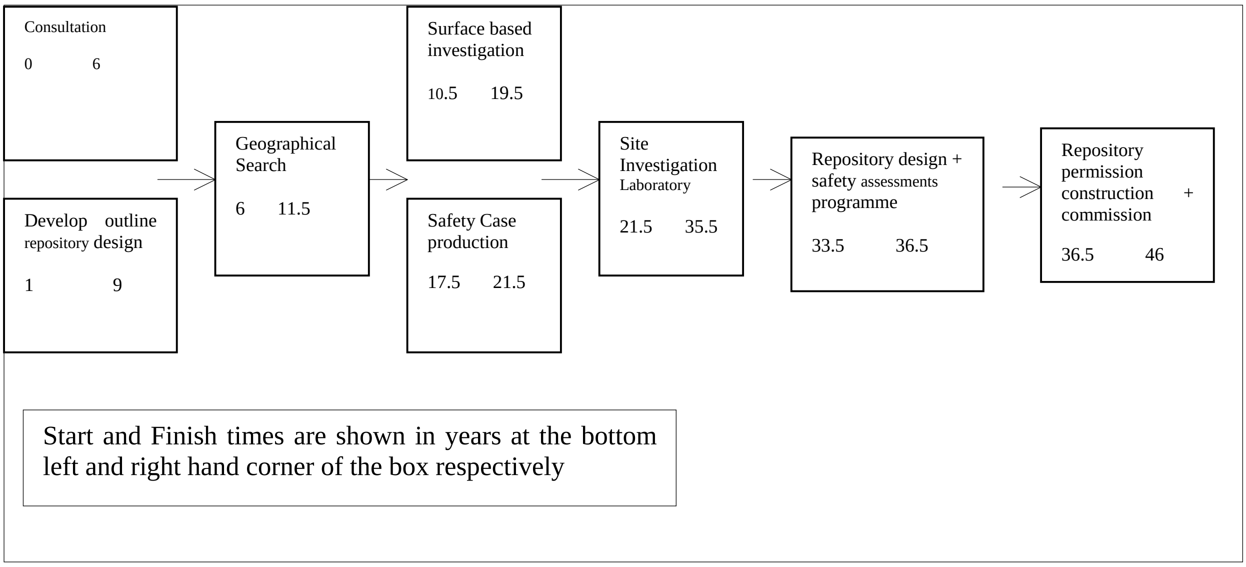
The disposability of plutonium wasteforms needs to be brought into consideration as early as possible in order to identify any significant issues for repository concept design and operation. One key aspect that seems relevant to our discussion on 6th June is the need to explore potential interaction between wasteforms, backfill and host rock.

Nirex have also investigated the issues associated with the co-disposal of UK's ILW inventory in shared facility with the UK's HLW/SF inventory, a recent paper is also included [Ref 2].

9. What timescales would Nirex envisage for the development of a definitive disposal concept and wasteform, and what lead-time should be allowed for the disposal option to become available?

Nirex has developed an integrated programme of research and site selection for separate repositories for ILW/LLW (in order to provide provisioning advice to customers) and HLW/SF (in order to gain a better appreciation of the key issues and drivers of a programme for a co-disposal facility).

A summary of a reference research and development programme for HLW/SF is shown below. This was developed by reviewing the Nirex ILW/LLW programme, the DETR HLW/SF study and programmes in other countries.



Critical path analysis of the reference HLW/SF programme suggests that activities relating to consultation and decision making will all lie on the critical path as well as those relating to site selection and investigation.

In order to address the House of Lords observation on the need for an integrated waste management approach the impact of other potential wastes on the reference HLW/SF programme has been assessed. It was felt that the addition of plutonium would increase the amount of R&D required and this work could be performed in parallel with other R&D activities already in the reference programme. Overall the inclusion of other wastes was not considered to extend the duration of the R&D programme or change the critical path activities.

10. Why should DTI have asked Nirex to provide a technical note on plutonium disposal? (when Nirex's mission has hitherto been only to cover ILW and LLW).

Nirex advises waste producers on packaging requirements for intermediate-level wastes (that contains nearly 8 tonnes of plutonium) based on its cement based phased geological disposal concept. Nirex has drawn on this experience and the safety assessment methodology that underpins the concept in order to identify the implications of declaring all or part of the stock piles of separated plutonium as waste.

Nirex prepared report in 2000 in response to a request for information from George Reeves (a member of RWMAC) [Ref 3]. In 2001 the DTI (a Nirex shareholder) requested further information, specifically on plutonium, based upon this work and another report was subsequently produced and issued in early 2002 [Ref 4].

11. Has Nirex done any comparative technical and economic study of the long-term storage and/or disposal of plutonium within irradiated, unreprocessed spent fuel compared to the equivalent management of separated plutonium?

Nirex has not performed any comparative studies on the long-term management of plutonium as spent fuel or as separated plutonium. We would like to stress that the preliminary work that we have done to date focuses on identifying the issues and implications [Ref 1] but purposely does not set out to identify any preferred options or recommendations at this stage.

Numbered references cited in Nirex's answers (copies of these were supplied to PuWG)

1. Implications of Declaring UK Separated Stocks of Plutonium as Waste. Nirex Technical Note, Document Number 374558 v5, Reference Number DK 05 70, Status – Interim, 26 March 2002.
2. Issues associated with the co-disposal of ILW/SF in the United Kingdom. S J King and M Poole. Proceedings of WM'02 Conference, February 2002, Arizona USA.
3. Scoping assessment of implications of reprocessing scenarios for disposal options. Paper to RWMAC. United Kingdom Nirex, Document 334004, May 2000.
4. Management of Plutonium: Disposal Considerations. Nirex Technical Note, Document Number 360756 v3, Reference Number DK 05 70, Status – Interim, 30 May 2002.

Glossary of Abbreviations

^{235}U	Uranium-235
^{238}U	Uranium-238
^{239}Pu	Plutonium-239
^{240}Pu	Plutonium-240
^{241}Am	Americium-241
^{241}Pu	Plutonium-241
ABWR	Advanced Boiling Water Reactor
AGR	Advance Gas-cooled Reactor
ALWR	Advanced Light Water Reactor
ANSTO	Australian Nuclear Science and Technology Organisation
AP	Advanced Passive
AP600 / AP1000	[Types of] Advanced Passive Light Water Reactor
APWR	Advanced Passive Water Reactor
APWR	Advanced Passive Water Reactor
BE	British Energy
BNFL	British Nuclear Fuels plc
BPEO	Best Practicable Environmental Option
BWR	Boiling Water Reactor
CCTV	Close Circuit Television
CND	Campaign for Nuclear Disarmament
CO_2	Carbon Dioxide
CTE	Company Technical Executive (BNFL)
DBT	Design Basis Threat
DEFRA	Department of Environment Food and Rural Affairs
DTI	Department of Trade and Industry
DTLR	Department of Transport, Local Government and the Regions
DU	Depleted Uranium
EA	Environment Agency
EH&S	Environment Health & Safety
EIA	Environmental Impact Assessment
EPR	European Pressurised Reactor
ESARDA	European Safeguards Research & Development Association
EU	European Union
Euratom	European Atomic Energy Community
GMB	General & Municipal Boiler Makers' Union
HAL/VHLW	Highly Active Liquor/ Very High Level Waste
HEX	Uranium Hexafluoride
HIVIEW	[A type of decision analysis software]
HLW	High Level Waste
HLW/SF	High Level Waste/Spent Fuel
HMIC	Her Majesty's Inspectorate of Constabulary
HMSO	Her Majesty's Stationary Office
HSE	Health and Safety Executive
I1	Immobilisation Option I1: New Build Immobilisation Plant
I2	Immobilisation Option I2: Immobilisation as Low Spec MOX
IAEA	International Atomic Energy Agency
ILW	Intermediate Level Waste
IMF	Inert Matrix Fuel
INMM	Institute of Nuclear Materials Management
IRIS	International Reactor Innovative and Secure concept
ISL	Immobilisation Science Laboratory

IWG	Interdepartmental Working Group (chaired by the Department of Trade and Industry)
kWh	Kilowatt hour
LLW	Low Level Waste
LMA	Liabilities Management Authority
LWR	Light water reactor
MoD	Ministry of Defence
MOX	Mixed oxide fuel
MRWS	Managing Radioactive Waste Safely (DEFRA consultation)
NGOs	Non Government Organisations
NII	Nuclear Installations Inspectorate
NUREG-0800	Nuclear Regulation (issued by the Nuclear Regulatory Commission in the US)
OCNS	Office of Civil Nuclear Security
p/kWh	Pence per kilowatt hour
PBMR	Pebble Bed Modular Reactor
PHWR	Pressurised Heavy Water Reactor
PIU	Performance and Innovation Unit (Cabinet Office)
Pu	Plutonium
PuO_2	Plutonium Dioxide
PuWG	Plutonium Working Group
PVC	PolyVinyl Chloride
PWR	Pressurised Water Reactor
R&D	Research & Development
R2	Reactor Option R2: UK Plutonium in existing UK reactors
R3	Reactor Option R3: UK Plutonium in new build UK reactors
RWMAC	Radioactive Waste Management Advisory Committee
S&S	Safeguards & Security
SAGNE	Standing Advisory Group on Nuclear Energy
SAGSI	Standing Advisory Group on Safeguards Implementation
SAP	Strategic Action Planning
SBR	Short Binderless Route
SCOPE	Standing Committee on Police Establishments
SDR	Strategic Defence Review
SEPA	Scottish Environmental Protection Agency
SMP	Sellafield MOX Plant
SMP2	Second Sellafield Mixed Oxide Fuel Plant
SNM	Special Nuclear Material
SO_2	Sulphur Dioxide
SSSG	Security & Safeguards Sub-Group
TEPCO	Tokyo Electric Power Company
THORP	Thermal Oxide Reprocessing Plant
TPS	THORP Product Store (a plutonium store)
U	Uranium
UK	United Kingdom
UKAEA	United Kingdom Atomic Energy Authority
UKAEAC	United Kingdom Atomic Energy Authority Constabulary
UO_2	Uranium Dioxide
US	United States of America
USDoE	United States Department of Energy
VPS	Vitrified Product Store