Packaging Options for Disposal of Plutonium Stocks in a Geological Disposal Facility (pre-conceptual)

Summary of Assessment Report

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Background and Context

As a result of historic reprocessing of spent fuels a stockpile of about 100 tonnes of separated civil plutonium exists, currently stored in the form of plutonium oxide powder. The current position of the Government and NDA is to view plutonium as a zero value asset and hold it in store. The eventual end-state of this plutonium is not defined, and therefore options for the long-term management of plutonium need to be explored. Consequently the NDA is delivering a project to define and evaluate alternative options to manage the plutonium. The NDA has a variety of drivers for the project, including the need to present strategic options with a defined end-point in order for NDA to meet its obligations under the Energy Act, the need to respond to stakeholders concerns, to provide assurance that the design of any future disposal facilities could accommodate the plutonium if required and to plan for continuing management of the materials.

The NDA has been exploring a number of alternative options for management of the plutonium, and has engaged with the regulatory bodies and a wider range of stakeholders to gauge views on the potential options. At the highest level, the credible options can be broadly defined as store prior to disposal, recycle to extract energy (e.g. in MOX or fast reactor systems) prior to disposal or disposal as soon as practicable. All of the options ultimately result in disposal of the plutonium, in one form or another. The work on options resulted in a credible options technical analysis paper which outlined the options, including some preliminary estimates of the costs and analysis of the uncertainties associated with them[1]. It concluded that it would be inappropriate to make final decisions on the plutonium management strategy at this time due to the high levels of uncertainty associated with waste disposal facility design, plutonium incorporation rates in waste packages and the market appetite for a recycle route. It recommended that further work should be undertaken to narrow the uncertainty bounds. It was therefore determined that pre-conceptual stage Letter of Compliance assessments should be carried out for a variety of defined packaging options to narrow the uncertainty associated with different wasteforms, acceptable incorporation rates in waste packages and disposal volumes.

The assessment of plutonium options has been carried out by Radioactive Waste Management Directorate (RWMD) of the Nuclear Decommissioning Authority (NDA), to provide advice to the customer, the strategy team within the NDA. RWMD provides a disposability assessment service, usually for Site Licence Companies with respect to proposals for packaging waste against the requirements of the Geological Disposal concept. This is known as the Letter of Compliance (LoC) assessment process. The LoC assessment process is typically used to demonstrate whether waste packages will be compliant with the proposed onward phases of waste management.

[1] NDA, *NDA Plutonium Topic Strategy – Credible Options Technical Analysis*, 30 January 2009.

Concept for a Geological Disposal Facility

The concept designs for a Geological Disposal Facility (GDF) are being developed, but ultimately the design of a GDF will be influenced by the geological setting provided by the host site. The site is not known at this stage and therefore RWMD is developing illustrative concepts applicable to a range of different geologies. RWMD has conducted generic quantified assessments for such a facility in higher strength rock to provide a baseline against which packaging assessments can be undertaken. The evaluation against other host geologies is not as advanced, and therefore more detailed evaluation of plutonium packaging options in these other host geologies may need to be considered in the future.

The concept for a GDF and its associated safety cases are being developed to accommodate all higher activity wastes, potentially including separated plutonium should it become a waste. A GDF design for higher strength rock is likely to incorporate disposal vaults for shielded ILW and LLW, vaults for stacks of unshielded ILW (e.g. 500l drums stacked in stillages, etc) and tunnels for individual emplacements of disposal canisters containing either vitrified High Level Waste (HLW), spent fuel (SF) and, should it be declared waste, plutonium. For the unshielded ILW (UILW) vaults, stillages and larger packages would be closely stacked in large arrays. Voids within these arrays would be backfilled with a suitable material prior to final disposal and closure of the facility. For HLW/SF and plutonium, the disposal canisters could be individually emplaced in disposal holes, accessed from tunnels, with the disposal holes lined with a clay backfilling material.

For the purposes of this assessment, RWMD has also considered another disposal arrangement whereby plutonium is packaged such that it can be disposed of through an ILW type disposal system utilising large arrays of packages stacked in vaults, with spaces backfilled with a cement based material. For ILW this arrangement is feasible by virtue of the relatively low radiogenic heat output of such waste materials. For ILW disposal RWMD is currently planning on the basis that the maximum acceptable heat output for a large array of ILW packages should be constrained to the order of $6W/m^3$ at the time of repository backfilling, equivalent to 3W per 500-litre drum package[2]. This is required to restrict the temperatures reached in the backfilling material. In contrast, for a HLW or SF disposal canister a much higher heat out put can be accommodated. A 1.2kW heat output constraint at the time of disposal is currently specified[3], by virtue of emplacement of individual disposal canisters. The constraint specified for HLW and SF disposal canisters is intended to maintain the inner surface of a bentonite backfill below 100°C, to maintain backfill and canister properties. Issues raised by this temperature constraint are being considered in work being conducted in consideration of high burn-up spent fuel and it is expected that future work will identify whether there is scope for revision of this constraint.

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[2] Nirex Report, *Generic Repository Studies – Generic Waste Package Specification Volume 2 – Justification*, Report N/104, June 2005.

[3] Nirex Report, *Specification for Waste Packages Containing Vitrified High Level Waste and Spent Nuclear Fuel*, Report N/124, December 2005.

Packaging Proposals

A broad range of wasteform production options and associated packaging solutions, including some further packaging sub-options, were defined by 'submission' documents provided to RWMD by NDA. The LoC assessment has been undertaken at 'pre-conceptual' stage, which is designed to allow comparisons between options without endorsement of any option. The plutonium wasteform production and related packaging options presented were:

1. Cement based wasteform within a 500l drum for vault disposal. A sub-option was to use a small inner can for a more concentrated wasteform, with the inner can centrally encapsulated in the 500l drum.
2. Polymer based wasteform within a 500l drum for vault disposal. A sub-option was to use a small inner can for a more concentrated wasteform, with the inner can and polymer wasteform centrally encapsulated in the 500l drum using cement grout.
3. Hot Isostatically Pressed (HIP) ceramic wasteform, packaged in a canister for vitrified HLW and further packaged in a disposal canister of size that would be required for PWR spent fuel. A sub-option was packaging of the HIP wasteform in a 500l drum for vault disposal.
4. Glass wasteform packaged in a canister for vitrified HLW and further packaged in a disposal canister of the size that would be required for PWR spent fuel. A sub-option was packaging the vitrified wasteform in a 500l drum for vault disposal.
5. Low-specification MOX ceramic packaged in a canister for vitrified HLW and further packaged in a disposal canister of the size that would be required for PWR spent fuel. A sub-option was packaging the low-specification MOX ceramic wasteform in a 500l drum for vault disposal.
6. Irradiated MOX fuel packaged in a disposal canister of size that would be required for PWR spent fuel. The use of 500l drums for this wasteform was not considered feasible.

Assessment Scope

The six defined wasteform options and their sub-options have been assessed through a reduced Letter of Compliance assessment process. RWMD would normally assess up to 16 technical areas for a Letter of Compliance assessment. A reduced scope of assessment was proposed for the current assessment, targeted on those features and issues that would differentiate between wasteform production and packaging sub-options. An initial consideration of the technical areas was made using an expert group within RWMD, which identified the following five technical areas for more detailed assessment, as follows:

- definition of the nature and quantity of plutonium for the different options and derivation of assessment data sheets, taking into account any expected radiogenic heat limits;
- criticality safety during transport and GDF operations;
- post-closure safety, including significance to long-term criticality safety in the GDF, and a literature review of international work to consider the merits of any other packaging/disposal options;
- assessment of nuclear proliferation risks associated with plutonium packaging options, mainly in relation to disposal;
- impact on GDF footprint and disposal costs.

In selecting these aspects for assessment, the expert group made the judgement that other aspects of transport and GDF operational safety could be more readily addressed through the design of the waste packages, the design of the engineered transport and disposal systems and operational management. RWMD expects that at some future point, when there is greater clarity over the waste management route for plutonium, specific proposals for packaging the plutonium would be presented, assessed across the wider range of technical areas and a complete disposability case generated.

Results and Conclusions

Given the reduced assessment, focusing on differences between options, the results and conclusions are intended to facilitate further development of plutonium disposition and are inevitably preliminary and indicative. Based on the results, all options are considered potentially disposable at this stage of assessment. In general the best results are achieved by the most robust and dissolution resistant wasteform types, but other factors are also relevant (e.g. impact on disposal costs and repository footprint, the container type, presence of depleted uranium in MOX, fission products in irradiated fuel, etc). The following detailed results and conclusions for the comparison of the options have been reached.

Option1, cement-based immobilisation in a 500l drum, appears to be viable from a disposability safety perspective, although would require production of hundreds of thousands of packages to meet likely constraints from radiogenic heat output, and from transport and operational criticality safety considerations. The cement wasteform greatly dilutes the plutonium, and thus offers some nuclear proliferation resistance.

Option 2, polymer-based immobilisation in a 500l drum, would also require production of hundreds of thousands of packages but appears to be the least desirable option on post-closure safety and proliferation risk grounds. Disposal of large quantities of polymer may be incompatible with geological repository safety, due to possible effects of the polymer degradation products on radionuclide solubility and sorption. The polymer wasteform is also considered to offer the lowest proliferation resistance of the options presented.

Option 3, HIP ceramic wasteform packaged in canisters for vitrified HLW and further packaged in a disposal canister similar to that for PWR spent fuel, appears to present the best option for disposability on safety grounds. A high plutonium inventory package could result from use of this option. To prevent criticality this option will rely on the non-plutonium components of the wasteform. However, preferential leaching of neutron poisons and concentration of plutonium after canister failure could theoretically result in criticality. Application of a disposal canister with very long life could ensure decay of Pu-239, but the U-235, which in-grows from Pu-239 decay, is also fissile. It therefore appears that post-closure criticality safety will be a key area for further work should high plutonium concentration wasteforms be pursued, and this may be a key factor ultimately affecting choice of disposal canister materials and/or limit contents. Disposal of HIP ceramics in 500l drums may also be viable, but at lower plutonium loadings due to heat output constraints.

Option 4, glass wasteform packaged in canisters for vitrified HLW and further packaged in a disposal canister similar to that for PWR spent fuel, is considered almost as favourable as option 3. Again, the use of 500l drums for vitrified plutonium may also be viable, but at lower plutonium loadings due to the heat output constraints.

Option 5, low-specification MOX ceramic packaged in canisters for vitrified HLW and further packaged in a disposal canister similar to that for PWR spent fuel, is considered almost as favourable as option 3 and may be more favourable in terms of post-closure criticality safety. With MOX ceramic the plutonium oxide is mixed with a much larger quantity of depleted uranium. In this respect MOX ceramics may be inherently less prone to future criticality events than options 3 and 4 due to the presence of U-238 diluting in-grown U-235. In-grown U-235 would be diluted down to Low Enriched Uranium through the presence of U-238 in the ceramic formulation. If necessary a lower concentration of plutonium in the MOX ceramic could be used to ensure an even lower subsequent enrichment from U-235 in-growth, but this would result in more waste packages for disposal.

Option 6, irradiated MOX fuel packaged in a disposal canister similar to that for PWR spent fuel, is fundamentally different to the other options since fission products are introduced and plutonium is consumed by irradiation, and it therefore requires a spent fuel packaging and disposal route. The assessment gives an acceptable result in comparison to other options, although it gives a technically poorer post-closure performance for radiological risk from the groundwater pathway than options 3, 4 and 5, since it is a spent fuel with the presence of some long-lived soluble fission products. However, it should be noted that MOX fuel would presumably be introduced as a replacement for standard PWR spent fuel that would otherwise require disposal, and in this scenario would not be creating additional fission products. In terms of post-closure criticality safety this option appears inherently better than options 3 and 4 due to the presence of U-238 diluting in-grown U-235, and better than all other options due to consumption of some of the plutonium during irradiation. This is also the most nuclear proliferation resistant option due to the presence of gamma radiation, however it should be noted that this advantage is time limited due to decay of short-lived fission products.

Disposal costs and GDF footprint

The assessment concludes that the use of several hundred thousand 500l drum packages with very low plutonium loading and disposal to a vault disposal system would present the lowest disposal costs and utilise the lowest disposal footprint, even when compared to use of several thousand spent fuel type disposal canisters. This is due to the relative efficiency of the stacked package disposal system (3-D arrays). This analysis is based on the concept design for a GDF which is based on a range of assumptions. It should be noted that the actual dimensions of the underground areas of a geological disposal facility will be determined by the exact inventory for disposal, the properties of the host rock and the geometry of features within it. In practice it may also be possible to build a geological disposal facility over a smaller area than indicated by this report, by building deposition tunnels or vaults on different levels. This would however depend on the geology of the site. Also, the cost estimates presented in this report do not address package manufacturing, storage and transport issues and associated costs. As indicated by published NDA work[1], these costs may be highly significant, particularly for options requiring use of large numbers of packages.

Optioneering

All options are considered potentially disposable at this stage of assessment and could be investigated in more detail. The report provides an analysis of the issues associated with each option, from the disposability perspective. It is considered that this will provide information to support future decision making. The results, particularly from the cost and footprint assessment, imply that optioneering to develop an optimum packaging and disposal system for plutonium disposal could be considered. For example, the ceramic, glass or low-specification MOX ceramic could be packaged in a lower specification container and disposal system than the disposal canister and deposition hole system, perhaps at concentrations significantly higher than considered in the current study for vault disposal. Such packages might be suitable for disposal in the tunnels used to access the disposal holes for spent fuel and HLW canisters, and backfilled using crushed rock. It should be noted that disposal of plutonium as irradiated MOX fuel would be an exception to this, since this option would need to be compatible with a spent fuel disposal system.

Nuclear Proliferation - Proliferation Resistance and Safeguards

The requirements for applying International Safeguards and security measures (physical protection) to a GDF are recognised. The extent to which it may also be necessary to apply the overarching general concept of ‘proliferation resistance’ to plutonium disposed to a geological repository remains an issue. Adoption of proliferation resistance could affect both packaging design and repository engineering, although at this stage it is unclear to what extent the general concept of proliferation resistance should be adopted and how it should assessed and quantified.

One of the major questions identified from the assessment of proliferation resistance is how to terminate Safeguards for plutonium, and whether this influences wasteform type or disposal method. It is recommended that this issue is discussed with Euratom/IAEA. The current assessment identifies post-closure as the area of greatest uncertainty from this perspective, in part due to the slow decay of fissile plutonium isotopes and the in-growth of U-235.

Next Steps

This report is issued to NDA and is anticipated to be used to inform decision making related to identification of preferred options for the disposition of plutonium stocks.