Packaging of Ponds Solids Legacy Fuels: Proposals for Cold Vacuum Drying and In-Container Vitrification

(Conceptual stage)

Summary of Assessment Report

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Introduction

The Pile Fuel Storage Pond (PFSP) and First Generation Magnox Storage Pond (FGMSP) at Sellafield contain a mixture of legacy uranium metal fuel and fuel derived wastes along with skips of zeolite, some isotope cartridges and large amounts of miscellaneous beta gamma waste (MBGW). Due to the inventories and the deteriorating nature of the aging storage infrastructure, the FGMSP and PFSP represent some of the highest hazards in the UK nuclear industry. Related uranium fuel waste held in the modern Fuel Handling Plant (FHP) pond is also considered here.

Sellafield Ltd held a technology screening workshop in 2011[1], from which they developed options for conditioning and packaging the legacy uranium metal fuel and fuel bearing materials from these ponds, namely encapsulation (using cement or polymer), cold vacuum drying, and in-container vitrification. The proposals for in-container vitrification (ICV) and cold vacuum drying (CVD) both employ novel treatment methods, and utilise non standard or modified waste containers or canisters.

The legacy fuel wastes include whole metal fuel, metal fuel bits, fuel cladding (Magnox and aluminium), cemented metal fuel bits and end-crops, post irradiation examination fuel samples in bottles, some irradiated graphite, a small amount of low enriched metal fuel. Dounreay Fast Reactor breeder material was excluded from the assessment due to uncertainty in irradiation history and inventory. Oxide fuels currently held in the PFSP, bulk sludge, MBGW, ion exchange and zeolite materials from the ponds are also excluded.

Encapsulation proposals (two cement encapsulation and one organic polymer option) were assessed for disposability by the Radioactive Waste Management Directorate (RWMD) in 2012[2]. This assessment addresses the remaining two conditioning and packaging options, CVD and ICV, completing the disposability assessments for the waste stream and facilitating future decision making by Sellafield Ltd.

Although not discussed in the technology screening workshop, Tokai Mura End Crops from the FHP pond are included in the current submissions from Sellafield

1 Nuclear Technologies plc for Sellafield Ltd, *STPTUP Technology Screening Workshop*, NT/722500801/R936 Issue 2, August 2011 (NDA Document Reference 14967768)

2 NDA, *Assessment Report for Encapsulation of Legacy Fuel and Fuel Bearing Materials from Sellafield Ponds* (NDA Document Reference 15722715)

Ltd[3,4] and the disposability assessment.

The fuel wastes comprise a mass of approximately 535 tonnes of uranium metal. Most of the material is accounted for in the UK Radioactive Waste Inventory although 78 tonnes of uranium in the FGMSP waste is not currently included in the Inventory.

The CVD option is expected to result in approximately 3400 canisters for disposal, contained in about 850 stillages.

The ICV proposal is anticipated to result in the order of 800 3m^3 box packages for disposal.

An assessment of disposability was undertaken for the ICV and CVD options by considering the compatibility of the proposed packages with RWMD waste package specifications, with the geological disposal system concept and the generic Disposal System Safety Case (gDSSC). Further information on the disposability assessment process is available elsewhere[5].

Waste Packaging Proposals

Conditioning and packaging activities are proposed to be carried out in the Sellafield Solid Treatment Plant (STP).

Cold Vacuum Drying

The proposed technique is based on the method used by the United States Department Of the Environment at Hanford to treat fuel wastes for interim storage, which produced a dried fuel waste sealed and inerted within a steel canister, enclosed within a 1.3cm thick multi-canister overpack.

Skips of legacy fuel waste would be recovered from the ponds and bulk sludge washed off prior to transfer to STP. At STP waste would be removed from a skip, using remotely controlled equipment, weighed, loaded into a washing tray and then low volume high pressure washed to remove sludge. After an initial draining/drying stage it would be loaded into a stainless steel can, a solid walled cylinder with grill ends to allow drying. After loading to a basket and transfer to a drying chamber a drying cycle would be used to attain moisture removal. The drying cycle would involve heating the can and waste material to 50^{o}C in an inert atmosphere and then cooling under vacuum to remove moisture.

Once the fuel material was dry enough the baskets would be loaded into a 5mm thickness, cylindrical stainless steel canister (1400mm high x 610mm diameter), inerted, and a cover welded to the canister. Since the canisters could become pressurised, they are designed to withstand a pressure of 30 bar absolute at 100°C. After weld testing and decontamination, canisters would be placed 4 to a stillage for interim storage in the Box Encapsulation Plant Product Store.

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3 Sellafield Ltd, *Submission to NDA RWMD for a Conceptual Stage Letter of Compliance for the In-Container Vitrification treatment of Legacy Fuel and Fuel Bearing Materials,* RP_BEP-873_PROJ_ 00109_A, March 2012, (NDA Document Reference 16225838)

4 Sellafield Ltd, *Submission to NDA RWMD for a Conceptual Stage Letter of Compliance for the Cold Vacuum Drying of Legacy Fuel and Fuel Bearing Materials)*, RP_BEP-B873_PROJ_00106_B, March 2012, (NDA Document Reference 16225645)

5 NDA, Guide to the Letter of Compliance Process, NDA Document WPS/650, March 2008

In Container Vitrification

Skips of legacy fuel waste would be removed from the ponds in a skip and after pre-treatment, possibly only drainage of pond liquor and some sludge, transferred to STP, weighed, and placed in a refractory-lined $3m^3$ box. Glass formers and haematite oxidant would be added as determined by the waste material type and weight.

Two to four graphite electrodes would be inserted into the glass former material and graphite flakes added between the electrodes to form a starter pathway for the current between the electrodes and allow formation of a melt pool. The resulting melt pool would extend into the waste material and as the molten material advanced, it would further melt the waste mixture as a glass matrix formed. The waste/glass mixture would attain a temperature between 1300 and 1500 degrees centigrade. At this temperature the waste would undergo a number of physical and chemical reactions which effectively oxidise reactive metals, destroy organics, decompose inorganic salts and mix the waste, reaction products and glass formers into a glassy matrix. Some ceramic and metal inclusions may be present but Sellafield Ltd asserts that these would be surrounded with vitrified material and so are unlikely to affect the product quality. A metallic iron phase would be expected to form at the base of the wasteform comprised of the melted skip and other non-reactive metal.

Processing time would vary according to the quantity of waste to be treated, the physical and chemical composition of the waste and product formulation requirements. However, it is estimated that this step will take approximately 30 hours per loaded $3m^3$ box. ICV treatment would be expected to result in creation of significant void space through volume reduction. SL would prefer not to fill the resulting void space.

A substantial off-gas treatment facility would be required creating secondary waste streams some of which might be fed back into the ICV process.

After cooling and finishing, including decontamination, the $3m^3$ ICV packages would be stored in Box Encapsulation Plant Product Store.

Outcome Of Disposability assessment

Cold Vacuum Drying

The proposal is not fully compliant with the requirements of the Generic Waste Package Specification (GWPS), the Level 2 Generic Specification for packages containing low heat generating waste and the geological disposal concept. The key issues preventing conceptual stage endorsement of the proposal are set out below:

Canister robustness

The assessment identified a very substantial shortfall in the canister performance under accident conditions. Only a small fraction of the available kinetic energy (<10%) is required to cause loss of containment in aggressive impacts for a 15m drop. Since the dried waste is unconstrained and un-encapsulated, significant release of activity could result from impact accidents. The potential for rupture of the pressurised canisters within Standard Waste Transport Containers (SWTCs) has not yet been demonstrated to result in acceptable releases, therefore transport safety cannot currently be demonstrated under accident conditions. Design basis accidents for the Operational phase of a geological disposal facility are assessed to result in unacceptable radiation doses to workers and the public. Redesign to provide adequate safety performance would be required before endorsement. Possible development options include strengthening the canister and/or providing secondary containment.

Canister dimensions

The CVD packages would be remotely handled and emplaced, requiring use of the SWTC with 285mm of shielding, to provide for acceptable external radiation dose rate during transport. The CVD canister design height is not compliant with the current designs for the SWTCs and the canister handling features are non-compliant with the current designs for the Geological Disposal Facility package receipt and handling systems. For endorsement these would either require design changes to the canisters or changes to the disposal concept through formal change control. The latter option would only be considered if there was suitable safety justification. The proposed stillage for the canisters would use the Sellafield twistlock pocket design which is not ISO compliant. The safety case for this design is still to be confirmed.

Canister transport

It is currently unclear whether carriage of the sealed CVD pressure vessel in a SWTC might be prohibited. If it is allowable it is unclear how pressure vessel status/registration would be maintained demonstrating the appropriate level of containment required of the canisters. Sellafield Ltd will need to demonstrate that such a case could be made and the tests necessary to ensure ongoing qualification/registration of the pressure vessels.

CVD waste properties

The wasteform is comprised of unconstrained waste, the geometry and corrosion state of which is known to be variable, from whole fuel to corroded fuel pieces. Some waste is currently cemented. Loose particles are likely to be present or form during handling or would form as a result of accidents. The variability of the waste could significantly affect releases on loss of containment under accident conditions. The assessment concluded that it remains to be demonstrated that all of the wastes are suitable for CVD disposal.

Criticality safety

Criticality safety for these packages of un-encapsulated, unconstrained fuel is not currently demonstrated. Waste streams containing graphite may prove particularly problematic, in this context, unless the material was removed. It was concluded that due to the non uniform arrangement of the material and the potentially large fissile mass, a package specific criticality case covering transport, operational and post-closure phases would be required before endorsement.

Post-closure phase

Assumptions for conditions in the post-closure phase results in relatively rapid corrosion of the canister and fuel waste, the lack of an encapsulating medium leading to direct release of radionuclides to the groundwater pathway. Rapid package and waste corrosion could also result in localised voidage in the backfill, potentially increasing groundwater flux through the resultant pathways, reducing the opportunity for actinide sorption and retention in the backfill medium. This more rapid actinide release would be expected to increase post-closure risk in the groundwater pathway compared with a similar encapsulated wasteform. However it is probably impractical to fill the canister void space.

<u>In-Container Vitrification</u>

This proposal represents the largest proposed disposal of vitrified ILW seen to date. Vitrified ILW wasteforms are not currently considered in the gDSSC. The compatibility of their disposal in the current disposal concept is being examined through the Change Control process. RWMD is also exploring if there are more optimal disposal concepts and will amend our disposal concept through formal change control if appropriate. We propose to undertake this work before endorsing such large scale application.

Overall, the proposal is not fully compliant with the requirements of the Generic Waste Package Specification (GWPS), the Level 2 Generic Specification for packages containing low heat generating waste and the geological disposal concept. The key issues preventing conceptual stage endorsement of the ICV proposal are set out below:

Reliability

Relatively novel, the ICV conditioning method for legacy fuel waste is at an early development stage. The proposal is based on only a small number of ICV trials, conducted using simulants for the waste, with varying outcomes. Further development work is required to understand the process controls required to reliably produce quality products, including the effect of waste loading, waste type and condition (including cemented waste). This is not unexpected at such an early stage of the process development. However taking account of the relative immaturity of the in-container vitrification technology compared that of cementation the assessment concluded that reliability of the process would need to be demonstrated before endorsement.

Wasteform properties

Reflecting the lack of ICV specific wasteform data, the release fraction (RF) used in impact accident safety analysis is based on a series of potentially conservative assumptions. A consequence of this RF and the high activity content of the wasteform is that the modelled radiation dose to Geological Disposal Facility operatives from Design Basis Accident faults does not meet our requirements. Determination of energy absorption and break-up characteristics of actual ICV products would allow realistic package specific RF values to be determined for accident safety analysis.

A key assumption for criticality safety is that ICV processing results in the fissile material uniformly distributed within the glassy phase of the wasteform, with little in the metallic phase. In order to investigate if this holds true ICV trials using a suitable stimulant (such as uranium) would be needed. Analysis of the resulting wasteforms would allow any future package criticality safety cases to take account of the actual level of homogeneity.

Criticality safety

Post-closure criticality safety is not yet demonstrated. Comparison of the maximum package fissile load with generic Upper Screening Levels for criticality for irradiated natural uranium and those calculated by Sellafield indicated that for uniformly distributed fissile material derivation of a package specific criticality safety case is feasible for the transport and operational phases but not for the post-closure phase. A post-closure package specific criticality case may still be attainable but, given the challenging inventory, RWMD require this to be demonstrated before conceptual stage endorsement.

Post-closure phase

In the post-closure phase, interactions between the glassy matrix and the backfill could reduce the pH and affect the NRVB backfill sorption characteristics, increasing assessed doses and risk through the groundwater pathway.

The heat output of a proportion of the packages would be too high for transport in 2040, though management of waste loading or a requirement for extended interim storage to about 2090 would allow compliance.

The consequence of localised voidage within the packages, arising from volume reduction on ICV processing, also needs further clarification. Voidage has the potential to affect the functions of the backfill, increasing groundwater flux and reducing actinide sorption characteristics.

Conclusions

The proposal from Sellafield Ltd covered two of five potential conditioning and packaging methods for fuel and fuel bearing wastes located in Sellafield FGMSP, FHP and PFSP ponds. A previous disposition assessment examined three encapsulation methods proposed for this waste.

This disposability assessment has concluded that, although they both show some promise, the proposals for CVD and ICV packing of legacy fuel wastes from Sellafield Ltd ponds are currently not consistent with requirements of the geological disposal concept in their current stage of development.

Conceptual stage endorsement of the proposals is therefore withheld pending the satisfactory resolution of issues set out in Action Points. Five Action Points were raised for the CVD proposal, and four Action Points were raised for the ICV proposal, to be resolved at Conceptual stage.

Concept change control is required to account for:

- Whether disposal of vitrified ILW packages is compatible with safe disposal in the current concept.
- The extent of localised voidage, associated with packages, which is compatible with the post-closure safety.

Conceptual stage endorsement of the CVD proposal is prevented by the chosen canister design which is not robust enough to provide the required safety performance for the chosen wastes or compatible with current transport and GDF designs. Criticality safety for all Geological Disposal Facility phases is currently not demonstrated.

For the ICV proposal the issues preventing conceptual stage endorsement are the reliability of the method at such an early stage of development, the undefined properties of the wasteform (such as uniformity of fissile distribution and properties affecting the impact RF) and post-closure criticality safety.

This assessment report was prepared by RWMD to assess the proposal from Sellafield Ltd against the technical, legal and policy framework of the LoC process. Draft assessment outcomes for this proposal were reviewed by the RWMD Nuclear Safety and Environment Committee (NSEC) on the 7th November 2012. NSEC supported the conclusions of the assessment. This report reflects their advice.