Nuclear Decommissioning Authority

Packaging of Sellafield Legacy Pond Solids – Options for Packaging of Fuel, Fuel Bearing Wastes and Isotope Cartridges

Summary of Assessment Report

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Introduction

This is a summary of an assessment carried out by Nirex in response to a pre-conceptual optioneering stage proposal from British Nuclear Group Sellafield Ltd (BNGSL) for the packaging of fuel, fuel bearing wastes and isotope cartridges from the Original Fuel Storage Pond and Original Magnox Storage Pond at Sellafield. These wastes form a significant component of the solid wastes present in the ponds.

Background

The Nirex mission is, in support of Government policy, to develop and advise on safe, environmentally sound and publicly acceptable options for the long-term management of radioactive materials in the UK. This includes all intermediate-level radioactive waste and some low-level radioactive waste (ILW and LLW).

As part of this role, Nirex sets standards and specifications for the packaging of ILW and LLW, based on its Phased Geological Repository Concept (PGRC)[1]. Nirex issues Letters of Compliance (LoC) when proposed packaging methods are assessed to be capable of producing waste packages that would be consistent with Nirex requirements for long-term management and protection of the environment. This process is intended to minimise the risk of inappropriate treatment, the need for future repackaging or the creation of a new legacy of wastes to be dealt with by future generations, with all the attendant safety, environmental and cost implications. The process of obtaining a Letter of Compliance is embedded in the regulators' arrangements for the conditioning and packaging of ILW, as described in guidance issued by the regulators[2,3].

In line with regulatory guidance, Nirex carries out independent assessment of the specific waste packaging proposals in particular to assess disposability of the proposed waste packages by consideration of requirements for future storage, transport and disposal as embodied in the Nirex PGRC.

1 *The Nirex Phased Disposal Concept*, Nirex Report N/074, July 2003.

2 *Improved Regulatory Arrangements for the Conditioning of Intermediate Level Radioactive Waste on Nuclear Licensed Sites: Provision of Advice to the Health and Safety Executive by the Environment Agency and the Scottish Environment Protection Agency*, Regulators' Position Statement, December 2003.

3 *Conditioning of Intermediate Level Radioactive Waste on Nuclear Licensed Sites: Provision of Advice by the Health and Safety Executive, the Environment Agency and the Scottish Environment Protection Agency*, Guidance to Industry, March 2005.

Wastes and Current Storage Arrangements

The Original Fuel Storage Pond at Sellafield was operated from 1951 to 1962 to de-can irradiated fuel from the Windscale Piles. Between 1957 and the early 1970's the pond was used for the storage or de-canning of Magnox, oxide and experimental fuels from a variety of reactors. The pond now contains residual sludge and a quantity of solid wastes and skips.

The Original Magnox Storage Pond was built in 1959/60 for the purpose of receipt, storage and removal of cladding from irradiated Magnox fuel. The pond now contains a considerable quantity of residual sludge, mainly generated by corrosion of Magnox cladding, but also a significant quantity of metal fuels and other fuel bearing wastes, skips (some modified to hold zeolite ion exchanger) and Miscellaneous Beta-Gamma Waste (MBGW). Much of the waste is contained in the steel skips, but some has been spilt onto the pond floor.

The bulk of the waste considered in the current packaging submission is uranium metal in various physical forms. The bulk fuel is mostly clad in Magnox alloy, and some clad in aluminium, although it is also possible that partially de-clad or unclad fuel will be present due to corrosion of cladding in the ponds. Uranium is also present as uranium bits, broken fuel bars, and as fuel element end crops. Some of the uranium bits and end crops have been cemented by a historical in-pond grouting process within steel bins inside the pond skips. Most of the uranium metal in the fuel and fuel bearing wastes is irradiated natural uranium, although a small quantity of low enriched uranium fuel is also present.

Considerable quantities of other materials such as Magnox swarf and lugs, steel and cement grout are considered in the current submission. The ponds also contain some isotope cartridges, originally used in the Windscale Piles and Calder Hall reactors to produce specific isotopes. The cartridges are clad in aluminium or Magnox and are similar in size to fuel elements.

It is noted that some of the wastes from the ponds are declared within the UK Radioactive Waste Inventory but most, in particular the bulk uranium metal fuels, are currently excluded. These are also currently excluded from the Reference Case inventory for the Nirex Phased Geological Repository Concept, which is a sub-set of the UK Radioactive Waste Inventory. The bulk fuel is not yet declared as waste. This assessment recognises this fact, but for convenience subsequently refers to all materials as wastes. For an ILW packaging process to be endorsed for the fuels, the fuels would need to be incorporated into the PGRC using the PGRC change control process. It is understood that other solid pond wastes, for example Miscellaneous Beta Gamma Waste and zeolite skips which are excluded from the current submission, will be subject to a future submission(s).

Scope of Assessment

Nirex has performed an independent assessment of proposed waste packaging options for fuel, fuel bearing wastes and isotope cartridges from the Original Fuel Storage Pond and Original Magnox Storage Pond at Sellafield, against the requirements for future storage, transport and disposal as embodied in the Nirex PGRC. This has been undertaken to identify the relative merits of different waste treatment options.

For submissions which request endorsement of a specific packaging proposal Nirex would normally provide an Assessment of Disposability necessary for demonstrating that the waste packages produced would comply with safety and environmental protection requirements for transport, handling and disposal of radioactive waste, as formulated by the regulators. Such a component of the Assessment Report could be used to produce a submission as part of the site/plant licensing process. However, the current submission is pre-conceptual in nature with a range of options presented. Endorsement is not sought at this stage, and consequently this Assessment Report does not provide an Assessment of Disposability. Consideration has been given to the disposability issues that are likely to be raised by the wastes and alternative encapsulation processes.

The assessment responds to the specific request from BNGSL, and subsequently only considers in detail the waste treatment options presented in the submission document. It does not consider in detail other ILW treatment options, and it does not consider alternative disposal concepts such as a High Level Waste /Spent Fuel (HLW/SF) disposal route. An alternative ILW treatment option could be based on dissolution of wastes to form a liquid or slurry waste, followed by some form of waste solidification and packaging. Such a process would remove reactive metals.

Considering that the wastes proposed include a considerable quantity of bulk irradiated fuel, one possible option for long-term waste management of some of the fuels could be disposal to a future High Level Waste/Spent Fuel (HLW/SF) facility. It would not be unreasonable to expect that this option be considered as an input to a Best Practicable Environmental Option assessment.

Nirex has developed a geological repository concept for HLW/SF, and has the tools to provide an assessment against such a management route. Such an assessment would consider the suitability of the fuel wastes for packaging in a form consistent with the HLW/SF concept and provide indication of potential impacts. Nirex has separately offered to provide an assessment against the HLW/SF waste management route.

British Nuclear Group's Proposed Packaging Options

As part of an overall strategy for removal and treatment of the pond solids, BNGSL is adopting a strategy that requires fuel and fuel bearing wastes to be treated by a separate process from other solid wastes in the ponds. This strategy has been selected to address the concern that it may not be possible or optimal to develop a single packaging solution to treat all of the wastes currently stored in the ponds.

Proposals for waste retrieval and transfer to processing facilities are not highly developed at this stage, but it is possible to identify components of this process, which are summarised below.

Original Fuel Storage Pond solids will undergo washing and segregation to facilitate export from the pond. These wastes will be removed from the skips (where the majority of the wastes currently reside) and be loaded into sacrificial 250-litre perforated liners within a new facility at the pond, and the liners transferred under water cover by flasks to the process building(s). The liners and wastes will be incorporated into waste packages. Nirex assumes that pond skips will be diverted for alternative processing. It is also proposed to transfer some of the non-standard fuels, primarily the enriched fuels, for sampling and analysis, before transfer to the processing building(s).

The Original Magnox Storage Pond wastes will be washed within the pond, with the intention of removing sludge before further treatment is undertaken. Other pre-treatment activities will be required, which may be undertaken at the pond or elsewhere. These activities are expected by BNGSL to include opening of closed containers and breaking up of cemented wastes. Wastes from the pond will be transported in the pond skips, and all Original Magnox Storage Pond skips will be deemed as waste for disposal. Skips would be incorporated whole into packages for $3m^3$ box packaging options, but for 500 litre drum packaging options BNGSL state that the skips would need to be size reduced or diverted for alternative processing. The wastes and skips would be transported under water cover within flasks from the pond to the process building(s). It is also proposed to transfer some fuel elsewhere for sampling and analysis.

BNGSL intended to reduce emphasis on the ability of the waste encapsulation process to maintain the integrity of waste packages by utilising annular containers. The 500 litre drum or $3m^3$ box would be of an annular design, incorporating two steel skins between which would be a cavity that would be filled with inactive cement grout.

Two waste conditioning concepts are presented in the submission, with a range of sub-options. These are summarised below.

Encapsulation Concept

The Original Fuel Storage Pond perforated sacrificial liners would be drained and loaded into 500-litre drums or $3m^3$ boxes. A frame may be used to facilitate efficient loading into $3m^3$ boxes. The Original Magnox Storage Pond skips and their waste loading would be drained and loaded into $3m^3$ boxes, one skip per box.

The wastes would be encapsulated using an alternative encapsulation matrix to the commonly used OPC-based cementitious grouts. BNGSL state that this has the purpose of reducing or eliminating waste/matrix interactions and to immobilise activity, resulting in a waste package with predictable and acceptable performance. Three families of alternative encapsulants have been identified:

- inorganic cement systems based on Calcium SulphoAluminate (CSA) cements or Magnesium Phosphate cements;
- organic polymers, thermoplastic or thermoset;
- Low Melting Point (LMP) metals.

Compaction Concept

BNGSL propose that the waste pre-treatments for the compaction concept would be similar to that for the encapsulation concept, except that Original Magnox Storage Pond skips would need an alternative processing route unless size reduced. BNGSL do not state how the sacrificial liners from the Original Fuel Storage Pond would be managed as part of the compaction concept.

The wastes would be placed into sacrificial cans, with the addition of a binder material. BNGSL studies have refined candidate binders to gypsum plaster, kaolin clay, magnesium hydroxide or CSA cement powder.

BNGSL propose that the filled cans would be supercompacted to form pucks. The pucks would be loaded into 500 litre drums or $3m^3$ boxes, and the voidage filled with a conventional cement grout, an alternative encapsulation matrix or even a void filler.

Assessment of Proposals

Generic Processing Issues

Uranium metal is known to corrode where water is available. Corrosion of the uranium in an encapsulated product can cause product expansion and degradation, generate an inventory of potentially dispersible corrosion products and under anaerobic conditions may generate pyrophoric uranium hydride after packaging. Other reactive metals such as Magnox and aluminium are also present in this waste. A waste treatment process will need to be developed to address these issues associated with packaging of reactive materials.

The wastes are stored under water and will be contaminated by sludge and may also retain pockets of water when drained. The ability to de-sludge and de-water wastes will be limited by the skip designs, and retention of materials in the skips if skips are not to be emptied prior to packaging. Some wastes, such as swarf and smaller solid objects may be particularly difficult to wash. Sludge is a both a potential source of mobile activity and of water. It may also affect the ability to successfully undertake many of the encapsulation options presented and to produce stable products, although some options may be more tolerant than others.

It is proposed to remove wastes from skips at the Original Fuel Storage Pond and to use disposable liners to transfer and house the wastes for packaging, since the Original Fuel Storage Pond skips are too large to package in $3m^3$ boxes without size reduction. It is not proposed to use this system for Original Magnox Storage Pond wastes, which form the majority of the proposed wastes. Nirex sees a number of potential advantages for long-term waste management for the use of liners, namely:

- it ensures wastes would be removed from the skips, allowing a better opportunity to reliably wash the solids of sludge, and to observe the composition and condition of the waste;
- it increases packaging options, for example to use 500 litre drums which cannot house a skip;
- it allows any waste requiring additional treatment to be separated and diverted;
- depending on liner design it could allow fuel elements to be aligned and oriented to some degree, perhaps using furniture, and for smaller 'units' of waste to be encapsulated minimising usage of certain encapsulants. There may be considerable benefits in encapsulating fuel at a small scale, and then loading units into boxes or drums for final packaging.

Treatment Options

The assessment has considered the potential advantages and disadvantages of the proposed treatment options, although it is noted that development work on some processes is more advanced than for others.

Based on existing evidence the alternative inorganic cements proposed do not appear to present any significant advantages over conventional OPC-based cements for application to the proposed pond solids. Inorganic cements may be the encapsulation option best suited to treatment of broken-up cemented uranium bits and Tokai Mura End Crops, which form a fraction of the proposed wastes.

Thermosetting polymers, such as vinyl ester styrene hold considerable promise for application to reactive metals, due to their non-aqueous nature and low permeability. However, their compatibility with uranium has not been demonstrated and there are uncertainties associated with radiation resistance for application to irradiated Magnox fuel and cobalt-60 cartridges which need to be resolved. Thermoplastic polymers do not appear suitable for encapsulation of the wastes proposed, due to their low radiation tolerance, propensity to melt when heated and flammability.

Low Melting Point metal encapsulants appear to present many potential advantages for immobilisation of reactive metals, relating to their unique combination of non-aqueous and inorganic nature and their inherent toughness. However, the specific alloys presented in the current submission have high density and are chemically toxic. It is conceivable that packages may exceed specified PGRC package mass limits by a large margin, creating significant issues for transport and operational safety. For application of this process, package design optimisation will be required to minimise use of these metals. Alternatively, other metal alloys that are less dense and less toxic could be considered.

From the specific range of options presented in the current submission, the compaction of waste with a binder appears to be the most flexible, and has potential to apply to all waste types (although not to the skips), if only a single process option is to be applied. The wasteform would probably not be of as good quality as some of the other options, when tailored to specific suitable wastes, since compaction may not be the optimum packaging process. The compaction process, like encapsulation using a water-based cement, may also allow formation of pyrophoric uranium hydride.

Packages containing wasteforms manufactured by a compaction process would rely more heavily for their performance on protection by the annular waste containers proposed. It may ultimately be necessary to consider the feasibility of re-design of the PGRC, for example to reduce potential drop heights, to meet safety criteria if compaction is pursued. Existing development work suggests water dampened binders produce the best compacted products, however this may not be compatible with preventing corrosion of uranium metal, and it may promote formation of pyrophoric uranium hydride.

Risks Associated with a Single Process Option

Although the wastes considered by the Assessment Report are only a component of the pond solids, they still comprise a wide range of materials, with diverse associated physical, chemical and radiochemical characteristics. For example, intact fuel elements present a significantly different waste packaging challenge to degraded cemented uranium residues, which will be broken-up on recovery. It is possible that no single waste treatment process will adequately suit this range of wastes, and BNGSL are encouraged to consider suitable processing routes for each distinct waste type. Selection of a single process option may allow a good quality product to be manufactured for some of the fuel, fuel bearing wastes and isotope cartridges, but probably not for all.

Waste Package Data Recording

The proposals for radiochemical inventory derivation focus almost exclusively on the bulk irradiated uranium metal fuel component of the wastes. The proposals for fuel inventory derivation look workable, although the ability to identify different fuel types from historical records and visual observation will probably be limited. The submission recognises the limitations in the currently available records of fuel irradiation and cooling history and, although BNGSL are confident in their ability to fill the gaps in this information, it is inevitable that certain pessimistic assumptions will be inherent in doing this.

Although the irradiated uranium metal fuel is likely to be the dominant contributor to the total radiochemical inventory of the wastes, it is not obvious at this time that other waste components could not also be significant contributors. For example, other waste components could also contribute significant inventories of certain activation products. It is not stated how the radiochemical inventory of these other waste components would be derived. In developing data recording proposals, BNGSL will need to devise methods for determining the radiochemical inventory of waste components other than just irradiated uranium metal fuel.

A number of different isotope cartridges were irradiated in the Windscale piles and Calder Hall reactor. BNGSL should consider which long-lived radionuclides could have been generated in significant quantity, and how they will be identified.

Generic Disposability Issues

Radiogenic heat loadings for packages containing irradiated fuel have the potential to exceed package limits set for the PGRC. Perhaps more significantly, average radiogenic heat loadings have the potential to exceed anticipated average heat loadings from ILW by up to two orders of magnitude. This may either have very significant design implications for the PGRC, requiring much reduced size disposal vaults or specific emplacement with other packages to dilute the heat loadings. Such changes to the repository concept would need to be taken forward through a process of change control. Alternatively, highly restrictive limits may need to be placed on package inventories, limiting the packaging efficiency and creating a larger number of waste packages than would otherwise be anticipated. As noted previously, a HLW/SF disposal concept which accounts for high radiogenic heat output may be more appropriate for this type of waste.

The methodologies for operational and post-closure criticality safety are being revised and developed. Nirex is developing generic post-closure criticality safety assessments to cover fissile wastes, including assessments to cover packages of irradiated natural uranium and packages of irradiated low enriched uranium. Proposals to package high concentrations of fuels may challenge these revised limits.

For the transport, operational and post-closure criticality safety assessments, low enriched uranium fuels will present the most restrictive limits. Segregation of the relatively small quantity of enriched fuels from the irradiated natural uranium is advised, since for combinations of irradiated natural uranium and low enriched uranium it is likely that the most restrictive assessment will need to apply.

The post-closure safety of the PGRC, like other waste disposal concepts or projects, is expected to be sensitive to migration of carbon-14 in gas form, especially if incorporated into methane. There is potential for this waste alone to exceed the radiological risk target if the carbon-14 inventory of the ponds wastes is released as methane at a high rate after disposal. Further work to underpin the understanding of this mechanism is being undertaken by Nirex, which may reduce uncertainties in the safety assessment. Alternatively, the selection of low permeability encapsulants by BNGSL may result in gradual exposure of the metallic wastes to aqueous conditions, with a correspondingly slow release of carbon-14.

The bulk fuel, which is not currently included within the Reference Case inventory for the PGRC, is assessed to increase the radiological risk for the groundwater pathway by 11%, due to exposure to radium-226 and other short-lived daughters of uranium-238. This represents a relatively small increase in risk. This increase in risk assumes the absence of organic species which may alter the solubility and sorption characteristics of U-238. It is conceivable that polymer degradation products could increase the solubility or decrease the sorption of uranium-238, resulting in a larger then expected increase in migration rate through the geosphere and increased risk. Conversely, ILW already contains significant quantities of organic materials which are addressed in the PGRC and factored into the risk assessment. Proposals to use polymer encapsulants at a large scale, particularly when used to encapsulate uranium, will require further more detailed consideration by Nirex if these encapsulants are to be pursued.

Conclusions

Nirex has assessed a pre-conceptual optioneering stage proposal from British Nuclear Group Sellafield Ltd (BNGSL) for the packaging of fuel, fuel bearing wastes and isotope cartridges from the Original Fuel Storage Pond and Original Magnox Storage Pond at Sellafield.

Most of the waste, the bulk fuel, is not currently declared as a waste in the UK Radioactive Waste Inventory, and does not form part of the Reference Case for the Nirex Phased Geological Repository Concept. For an ILW packaging process to be endorsed for the fuels, the fuels would need to be incorporated into the PGRC using the PGRC change control process.

The assessment responds to the specific request from BNGSL, and subsequently only considers in detail the waste treatment options presented in the submission document. It does not consider in detail other waste ILW treatment options, and it does not consider alternative disposal concepts such as a High Level Waste /Spent Fuel (HLW/SF) disposal route. It is understood that BNGSL will need to undertake a Best Practicable Environmental Option assessment, and the HLW/SF disposal concept should be included as one of the potential options for these bulk fuels, indeed the Assessment Report identifies technical reasons (e.g. radiogenic heat loading) why this route may be more appropriate. Bulk fuels packaged in 500 litre drums and $3m^3$ boxes are predicted to be non-compliant with the Generic Waste Package Specification and associated safety assessments.

The ability to de-sludge and de-water wastes will be an important factor. Removal of water and sludge will be limited by the skip designs, and retention of materials in the skips, if skips are not to be emptied prior to packaging. For a number of reasons, Nirex favours skip emptying and use of sacrificial liners. All skips would then need to be directed for more appropriate processing.

The potential advantages and disadvantages of treatment options have been assessed, and are discussed in detail in the Assessment Report. Reactive metals, uranium in particular, will corrode where water is present in encapsulated products raising a number of issues. A waste treatment process will need to be developed to address the issues associated with packaging of reactive materials.

The wastes comprise a wide range of materials, with diverse associated physical, chemical and radiochemical characteristics. It is possible that no single waste treatment process will adequately suit this range of wastes, and BNGSL are encouraged to consider suitable processing routes for each distinct waste type. Selection of a single process option may allow a good quality product to be manufactured for some of the fuel, fuel bearing wastes and isotope cartridges, but probably not for all.