NDA Strategy Magnox Spent Fuel

(Conceptual Stage)

Summary of Assessment Report

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Background

The current NDA strategy for the management of spent Magnox fuel is based on reprocessing using the existing facilities at Sellafield. This strategy is implemented through the Magnox Operating Programme (MOP), the intention of which is to ensure that all Magnox spent fuel is reprocessed by December 2020. It is recognised however that the Magnox reprocessing plant is a complex and ageing facility. While every reasonable effort would be made to recover from failure of any component of the plant, it is also accepted that it may be uneconomical to replace some critical plant components. Recognising that Magnox fuel is not suitable for extended storage in water, NDA, supported by Sellafield Ltd and Magnox Ltd, has developed a range of contingency options in the event of such a failure.

One of the contingency options to Magnox reprocessing is based on retrieval of the fuel from wet storage, followed by drying and sealing into stainless steel canisters. These canisters would then be stored in a purpose-built storage facility on the Sellafield site pending a future management decision. One possible future management option would be direct disposal within a Geological Disposal Facility (GDF).

At the request of Sellafield Ltd, Radioactive Waste Management Limited (RWM) completed a disposability assessment for intact Magnox fuel packaged using sealed stainless steel canisters in 2010. One of the key findings from that assessment was that further work was required to demonstrate the feasibility of the fuel drying and containerisation process. Since that time, Sellafield Ltd has carried out significant research and development to substantiate the feasibility of the process. That development work was initially focussed on intact Magnox fuel that would be retrieved from the Fuel Handling Plant (FHP), but it was also latterly extended to consider application of the process to corroded Magnox fuel that exists in the First Generation Magnox Storage Pond (FGMSP).

NDA has requested RWM to provide an updated conceptual stage disposability assessment based on the current status of the contingency option described above. The assessment is not based on a current submission from Sellafield Ltd, but upon a number of reports provided to RWM by Sellafield Ltd. It should be noted that while significant work on the contingency option has been carried out, the FHP and FGMSP fuel drying projects have been halted, in 2012 and 2014 respectively, and no work is currently being carried out. It is therefore not the aim of this assessment to provide endorsement against specific Sellafield Ltd proposals, should these meet RWM requirements. Similarly, RWM has not raised new Compliance Gaps or Action

Points, although where compliance gaps remain[1] for the current stage of assessment they are restated, as are the existing Action Points from the 2010 assessment.

The objectives of this conceptual stage assessment are to provide NDA with:

- An update on progress made with the maturity of the fuel drying and containerisation process to support future strategic decision making;
- An updated assessment of disposability in accordance with the Joint Regulators' Guidance to Industry; and
- Supporting advice on the disposability of bulk Magnox fuel recovered from both FHP and FGMSP, in the form of an Assessment Report.

Further information on the Disposability Assessment process is available elsewhere[2].

RWM Reference Basis for Assessment and Endorsement

The Disposability Assessment process considers the compatibility of the proposed packages with the requirements for safe long-term management, including interim storage at the site of arising, transport, emplacement and potentially extended storage underground, and disposal. The current reference basis for such an assessment is the documented disposal system concept and safety case for a GDF derived from the generic Disposal System Safety Case (DSSC).

The general requirements placed on waste packages for disposal in a GDF are embodied in the Generic Waste Package Specification (GWPS)[3]. Further requirements for particular types of waste package are embodied in the relevant Waste Package Specification (WPS). In the case of the bulk Magnox fuel waste packages, the relevant WPS is the Generic Specification for Waste Packages containing High Heat Generating Waste[4].

Scope of the Assessment

Packaging Process

Nature of the Waste

The waste is spent uranium metal fuel clad in Magnox alloy, referred to subsequently as bulk Magnox fuel, from Magnox power stations in the UK. Following advice from Sellafield Ltd, the RWM assessment is based upon an estimate of the spent fuel that would potentially remain following a failure in the Magnox reprocessing plant, which proved uneconomic to repair, approximately one year ahead of the currently planned completion of Magnox reprocessing in 2020.

The material covered in this assessment, which has been extended relative the earlier 2010 assessment that covered just FHP material, includes both FHP and FGMSP bulk Magnox fuel material. The FHP material is not in the UK Radioactive Waste Inventory (UKRWI) as it is not declared as waste (the present plan under MOP9 being to reprocess all the FHP Magnox material). The FGMSP material is

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[1] Compliance gaps were not used by RWM at the time of the 2010 assessment. Where they would have been used under the current assessment format they have been added for consistency with the current assessment format.

[2] RWM, *An Overview of the RWM Disposability Assessment Process,* WPS/650/03, April 2014.

[3] NDA, *Generic Waste Package Specification*, NDA Report NDA/RWMD/067, March 2012.

[4] RWM, *Geological Disposal: Generic Specification for Waste Packages containing High Heat Generating Waste*, WPS/240/01, February 2016

included in the UKRWI as part of waste stream M2D300 'Legacy Ponds Fuel', the latter is not planned for reprocessing under MOP9.

The bulk Magnox fuel held in the FHP (and what currently remains at Magnox power stations) is relatively well defined and characterised. For the purposes of this assessment, Sellafield Ltd has estimated this inventory to consist of 463 tU of fuel from 4 reactors: Calder Hall; Wylfa; Hinkley Point A and Dungeness A. More than half of the fuel is from Wylfa (280 tU), along with 94 tU from Calder Hall. The remaining 89 tU is classified as 'corroded' fuel from all four of the above reactors. This inventory is based on an assumed reprocessing end date of 2018 and current annual Magnox reprocessing forecasts; the actual inventory of FHP fuel that could require drying is subject to considerable uncertainty, dependent upon the success of the MOP in achieving its goal of reprocessing all suitable Magnox fuel by its planned end date of 2020.

The material from FGMSP is much less well defined than that from FHP. The facility pre-dates FHP and being open to air and having less well controlled water chemistry for periods of its operation has resulted in more significant degradation of the stored fuel. Sellafield Ltd has stated that only bulk Magnox fuel elements and un-cemented uranium bits should be considered as being inputs to the fuel drying and packaging process considered in this assessment, all other materials will be screened out by visual inspection during the recovery and sorting process. Data provided by Sellafield Ltd indicates that this could amount to some 200 tU Magnox fuel and fuel bits following the drying and packaging process, and this has been carried forward as an assumption in the current study.

Waste Processing and Packaging

The proposals for packaging intact Magnox fuel from FHP involve retrieval of individual fuel elements from wet storage for transfer to a Fuel Drying and Storage Facility that would be located either within FHP or elsewhere on the Sellafield site. The initial step would be to subject the fuel elements to deluge washing to remove any adherent sludge deposits, followed by draining of the residual water. Twenty six fuel elements would then be placed in a stainless steel basket in a vertical orientation in a square array. This basket would then be placed into a stainless steel Magnox fuel canister, similar to the design currently used for vitrified product at Sellafield. A cold vacuum drying process would be utilised to dry the fuel elements inside the Magnox canisters. The canister lid, which incorporates a heat shield and gas port, would then be placed on to the canister body, and welded in place. The canister would then be purged of weld gas and back-filled with high purity inert gas at atmospheric pressure. A closure plate would be applied to the gas port, which would be welded in place to form a high integrity sealed container. The finished canister would then be exported to the dedicated dry store for interim storage.

The process for FGMSP material would be similar to that described above for intact FHP fuel, albeit with modified basket arrangement to handle the broken fuel pieces. It is currently proposed to dry the FGMSP material in the baskets inside a dedicated drying facility prior to the baskets and liner being placed in the Magnox canister and sealed as described above for FHP material. This is to maintain throughput while allowing for the more demanding drying conditions of FGMSP material. The more demanding drying conditions are a result of the greater surface area and presence of residual sludge from corrosion on the surface of the FGMSP material.

The containerised fuel store is planned to be based on a modular dry vault store, similar in design to the existing facility for the storage of vitrified High Level Waste canisters at Sellafield, where the canisters are stacked in a series of storage tubes. Within the fuel store, up to five canisters would loaded into a storage tube, where they could be held for a period of up to 100 years. The storage tube atmosphere would be monitored to detect any leakage from a canister. The store environment would be passively ventilated and designed such that sufficient convective cooling would be provided irrespective of the store loading.

The containerised fuel would be stored until a GDF becomes available. Current planning assumptions indicate that a GDF would be available to receive spent fuel packages from the year 2075. The finished product store would therefore be designed to ensure that the packages are safely stored in good condition over this extended time period. At the end of this storage period, it is assumed that the stainless steel Magnox canisters would be retrieved from the modular store for overpacking, 3 at a time, within a high integrity disposal container for onward transport to a GDF. This assessment has assumed the disposal container would be manufactured from copper for disposal in High Strength Rock GDF and from steel in the cases of a Low Strength Sedimentary Rock or Evaporite Rock GDF, in agreement with RWM's published geological disposal concepts.

Assessment Inventory and Number of Packages

Since the original disposability assessment was completed in 2010, the assumed quantity of fuel that could remain in FHP following a cessation of reprocessing has been reduced from ~1,000 tU to the 463 tU as a consequence of continued reprocessing. In addition, as a consequence of the development work completed by Sellafield Ltd, the number of fuel elements that could be accommodated in a single Magnox fuel canister has been increased from 24 to 26. Development work on the design of a UK spent fuel disposal container has demonstrated that up to three Magnox fuel canisters would be packaged within each disposal container, compared to just two considered in 2010. These developments have resulted in a significant reduction in the number of disposal containers estimated to be required for the disposal of FHP material. However, as described above, Sellafield Ltd has now also proposed to extend the fuel drying process to encompass FGMSP material, which offsets some of this reduction.

The 463 tU from FHP can be estimated to be equivalent to ~39,500 fuel elements, which would translate to around 507 waste packages for disposal to the GDF. Similarly, the predicted 200 tU of FGMSP material would result in 112 disposal containers. This gives a total of ~620 packages. This compares to ~1,800 packages assumed in the 2010 disposability assessment, giving an overall reduction of 65%.

Assessment of Disposability

Waste Package Properties and Performance

In the case of FHP material the wasteform is the Magnox fuel elements held in an inert gas atmosphere within the Magnox fuel canister. The properties and evolution of the wasteform will be highly dependent on the efficiency of the cold vacuum drying process. Insufficient fuel drying would allow ongoing corrosion of Magnox and uranium metal, as well as radiolysis of water, leading to hydrogen generation and pressurisation of the stainless steel canisters. In turn, the hydrogen overpressure would support the formation of uranium hydride. The success of the drying process is therefore critical to ensuring a passively safe wasteform.

Sellafield Ltd has undertaken extensive drying trials on intact Magnox fuel, which demonstrate that the cold vacuum drying process will result in reproducible and sufficiently low levels of residual water. The case is less well made for corroded or damaged fuel, where water has entered the interspace between the Magnox cladding and the fuel through pinholes. Similarly, the case has not yet been made for FGMSP material where significant cladding corrosion and sludge layers present a more significant drying challenge. Further work therefore remains to be completed in this area to support the disposability of the dried fuel in the proposed stainless steel Magnox canisters.

The Magnox fuel canister has been designed by Sellafield Ltd as a pressure vessel, with a design pressure limit that is significantly greater than the pressure that could be generated from the bounding case consequences of inadequate drying and the resulting gas produced from corrosion reactions of the residual water.

The full definition of the Magnox canister design, specification of the upper gas pressurisation design limit and demonstration of conformity with relevant pressure vessel codes was raised as a Conceptual stage Action Point in the 2010 disposability assessment. As uncertainty still remains at the current time in terms of the effectiveness of the drying process and the upper design pressure limit for the Magnox canister, this Action Point remains open and precludes endorsement at the conceptual stage, since it is fundamental to demonstrating passive safety and suitability for disposal in a GDF.

The spent fuel disposal container being developed by RWM is being designed with the aim of maintaining containment under all credible design basis accidents. For such packages containing three Magnox canisters, no release of gases or radionuclides is expected to occur until well into the post-closure phase when the containers would eventually degrade as a consequence of long-term corrosion.

Compliance with the Transport System Design and Safety Case
It has been assumed that each disposal container (holding three Magnox canisters) would be sealed within a Type B transport flask known as the Disposal Container Transport Container (DCTC) for transport from Sellafield to a GDF. This transport package has been evaluated against the transport system design and the IAEA Transport Regulations in terms of radionuclide and fissile content, dose rates, heat output, pressurisation under normal conditions and containment under both normal and accident conditions. The assessment concluded that these packages should be compatible with the requirements of the IAEA Transport Safety Regulations, provided that a case can be made for the safe transport of potentially pressurised containers. As already highlighted, this case is likely to rely upon the sound engineering design of the Magnox canisters, coupled with an effective fuel drying process. This is recognised as being a potentially greater challenge for the transport of packages containing FGMSP material.

Compliance with Engineering Design and the Operational Safety Case
On receipt at a GDF, the disposal containers would be removed from the transport flask (DCTC) for onward handling and emplacement into the final disposal location, followed by backfilling with buffer materials. An operational safety assessment has been undertaken to evaluate the risks of handling the Magnox packages relative to the generic operational safety case that underpins the DSSC. This assessment identified that packages containing spent Magnox fuel should be compatible with the GDF engineering design and safety case provided that the fuel drying process and container design can be fully substantiated. Any pressure generated within the packages must be demonstrated to present no danger and hence comply with the requirements of the PSSR (Pressure Systems Safety Regulations 2000). These requirements are again reliant upon stringent canister/waste package design and an effective fuel drying process, neither of which has been fully underpinned at the current time. This is expected to be achievable for intact fuel from FHP based on the initial findings of the Magnox fuel drying trials and existing canister design development work. However, this situation is less certain for FGMSP material for which the drying and containerisation development work is less well substantiated.

A package-specific criticality safety assessment would be required to establish the safety of containerised Magnox fuel during the operational phase. With the majority of Magnox fuel being fabricated from natural uranium, this is not considered to be a significant challenge. It is recognised that small quantities of slightly enriched uranium have been used in the manufacture of historic Magnox fuel, some of which could be present in the legacy FGSMP material. Nevertheless, it is expected that it should be feasible to demonstrate criticality safety during the operational period, even for slightly enriched Magnox fuel, based on the exclusion of moderator (water) from the high integrity disposal containers.

Compliance with the Environmental Safety Case

The emplaced packages would be expected to provide containment of radionuclides for many thousands of years into the post-closure phase. For a GDF in High Strength Rock or Low Strength Sedimentary Rock, the bentonite-clay based buffer materials emplaced around the disposal containers are designed to limit container corrosion rates by providing a low permeability environment. In the case of HSR, this would prevent the access of potentially corrosive sulphur species to the surface of the copper disposal containers. Significant radionuclide decay would be achieved prior to eventual through-wall corrosion of the packages. The buffer material would then be expected to provide a further function of limiting the migration of radionuclides from the packages by sorption retardation, whilst allowing the passage of gases generated from metal corrosion and radiolysis through diffusion or pathway dilation (depending on the rate of gas generation). For a GDF in Evaporite Rock, the lack of water would provide very low corrosion and extended containment times.

The 2010 disposability assessment highlighted that the potential gas source term that could be generated by the Magnox packages is significant when compared to the oxide-based spent fuels that have previously been considered by RWM in the Environmental safety Case. This is because the uranium and Magnox metals that comprise the Magnox fuel would be expected to corrode relatively rapidly on contact with groundwater following a breach of containment, resulting in the generation of hydrogen gas. This was flagged as a potentially significant challenge to the viability of the proposed disposal plans. This was because at that time it was considered that the gas produced could impair the performance of the buffer material, for example by creating permanently open migration pathways.

The understanding of the performance of bentonite-based buffer materials has moved on since 2010. The current expectation is that any dilation in the bentonite clay due to elevated gas transients would tend to re-seal following the passage of gas rather than remain as open pathways. Furthermore, it is recognised that the rate of gas generation is strongly coupled to the availability of water in such systems and this, rather that the potential corrosion rate of Magnox or uranium, limits the actual corrosion rates and hence the expected rates of gas generation. Gases are anticipated to be generated during the post-closure phase from the chronic corrosion of many thousands of steel waste containers (or their inserts in the case of copper containers) and the engineered barrier system would be designed to allow for this. Therefore it is now considered that the Magnox fuel packages would not challenge the performance of the bentonite buffer.

The assessment examined the relative effect on post closure safety of direct disposal against disposing of the vitrified waste and ILW products from reprocessing of the same quantity of fuel. This identified a number of post-closure benefits and detriments from direct disposal of Magnox spent fuel when compared to reprocessing the same quantity of fuel. Direct disposal will reduce the potential risks from C-14 gas because C-14 would decay significantly before the sealed (gas tight) disposal containers would be expected to fail through corrosion. Direct disposal also has the added benefit that it avoids radionuclide discharges during reprocessing and the associated environmental impacts, although for long-lived species such as I-129, any environmental impact would be deferred to a much later timescale.

In summary, it has been demonstrated that the packages containing dried Magnox fuel could be shown to be compatible with the Environmental Safety Case provided an appropriate period of containment can be demonstrated.

Package *Optimisation*

A number of areas of potential optimisation have been identified during the course of the RWM disposability assessment, which NDA may wish to consider in the development of its contingency to cope with the loss of Magnox reprocessing.

The current disposability assessment has been undertaken on the basis that the Magnox canisters would remain hermetically sealed following the period of on-site interim storage at Sellafield. However, RWM does not require the canisters to be sealed for transport and disposal since a disposal container would be used that would fulfil the required containment safety functions. There are a number of potential benefits that could be realised from venting the Magnox canisters prior to packaging in the disposal containers, in particular, ensuring that there would be no need to handle pressurised packages, as any residual water from incomplete drying will have reacted or been removed from the canister during the storage period at Sellafield.

It is also assumed that the Magnox fuel would be consigned to a GDF as a high heat generating waste. However, the heat output and fissile content of Magnox spent fuel are very much lower than the spent fuel and vitrified HLW for which the high heat generating waste disposal concepts have been developed. Magnox fuel may therefore be suitable for disposal using an alternative approach, for example in suitably spaced arrays within vaults. NDA and RWM need to work together to better understand the need for development of suitable containers for storage, transport and disposal, and the associated time, cost and risk before an equivalent LHGW disposal option could be taken forward.

Summary of Previous Assessment

The previous disposability assessment in 2010 concluded that it should be feasible to safely transport and handle the disposal packages containing bulk Magnox fuel canisters. This conclusion was based on three key points, all of which remain valid at the current time:

- Magnox fuel elements can be adequately dried following retrieval from wet storage. This is necessary to ensure that the fuel elements remain in a passively safe condition since water would otherwise promote corrosion of the metallic Magnox and uranium, leading to the generation of hydrogen gas inside the fuel canister.
- The stainless steel fuel canisters, which act as the primary containment for the fuel elements can be shown to withstand all credible gas pressures that could be generated as a result of internal radiolysis and fuel element corrosion. This is necessary since failure of the canister could lead to the release of a significant inventory of activity and result in spontaneous ignition of any uranium hydride formed within the canister.
- The final disposal packages are capable of maintaining containment of the contents under all credible routine and accident conditions over the timescale covering transport to, and emplacement of the packages in, a GDF. Again, this is important due to the serious consequences of any loss of containment of the package contents during transport and handling operations.

Conclusions

The main conclusions from this disposability assessment are summarised as follows:

1. The cold vacuum drying process has been demonstrated for the conditioning of intact Magnox fuel from FHP, although some questions remain in terms of quantifying the level of water carry over.
2. The effectiveness of the cold vacuum drying process and the associated qualifying pressure rebound test has yet to be fully demonstrated for degraded and corroded Magnox fuel from FHP and FGMSP.
3. At the current point in time, it is not clear whether the contingency option of drying and containerising Magnox fuel is suitable to encompass the full inventory of FHP material that could remain if reprocessing were to cease and the Magnox fuel components from FGMSP defined by Sellafield Ltd. The need to ensure sufficient dryness is fundamental to the success of this option since this is the key factor in making a passively safe wasteform that would comply with requirements.
4. Further development work is required to fully underpin the cold vacuum drying process and pressure rebound test to allow a maximum level of water carry over to be defined so that the maximum design pressure can be defined for the Magnox canister. It is recommended that this work is brought to completion in order that a definitive position can be taken on the suitability of the packages containing both FHP fuel and FGMSP material for direct disposal in a GDF.
5. It remains necessary to substantiate the design of the Magnox fuel canisters to accommodate the design pressure that could be generated from the cold vacuum drying process. A single Compliance Gap and Action Point that relates to the Magnox fuel canister design remains to be addressed before the proposals could be endorsed by RWM at the Conceptual stage.
6. Development work undertaken by RWM since 2010 confirms that a disposal container could be developed that would fulfil all of the functional requirements for containment.
7. There remains an issue associated with compliance with the Pressure System Safety Regulations and this would require further container design substantiation to support the transport and operational safety cases.
8. Overall, it is concluded that it should be feasible to dispose of packages containing dried Magnox fuel, but this is still provisional on a robust demonstration of the fuel drying process for all of the proposed material.
9. A number of potential opportunities for packaging optimisation have been identified during the course of this disposability assessment and NDA is recommended to work with Sellafield Ltd and RWM to consider these in more detail to support the development of contingencies for Magnox reprocessing.