Periodic Review of Letters of Compliance for Packages Manufactured at Sellafield Magnox Encapsulation Plant

(Post-Final stage)

Summary of Assessment Report

Issue date of Assessment Report: 30 March 2010

Background

The Radioactive Waste Management Directorate (RWMD) of the Nuclear Decommissioning Authority (NDA) provides an assessment service for Site Licence Companies with respect to proposals for packaging waste against the requirements of a Geological Disposal Facility. This is the Letter of Compliance (LoC) assessment process. Full endorsement of such proposals is signified by the issue of a 'Final stage LoC'. The Final Stage LoC typically forms a component of a Site Licence Company's Radioactive Waste Management Case, which is expected to be prepared to obtain regulatory approval for implementation of the packaging proposal and manufacture of waste packages.

The issue of a Final stage LoC by RWMD indicates that waste packages manufactured in accordance with a proposed process, will be disposable when judged against the requirements of geological disposal. The LoC also provides a key component of the package record that will be needed for interactions with the disposal facility operator at the time of disposal. However, the issue of a Final stage LoC is not a one-off event but rather an initial step in the process of the long-term management of packaged radioactive wastes. Maintenance of the continued validity of the LoC is therefore an essential component of the strategy for managing the risk that waste packages will not remain acceptable for future disposal.

Following issue of the Final stage Letter of Compliance (LoC) and on receipt of any necessary regulatory permissions, it is anticipated that the waste packager will manufacture waste packages in accordance with the endorsed proposals and to an agreed Waste Product Specification. Though the Final Stage LoC is not necessarily required before the regulators will accept a Radioactive Waste Management Case, the LoC is considered to be the most appropriate means for demonstrating that waste packages will be compliant with the onward phases of waste management under development by RWMD.

It is generally expected that the currency of Final stage LoCs will be reviewed periodically. The periodic review provides the means for ensuring the continued validity of Final stage LoCs over the extended period from endorsement of a packaging proposal to the time when waste packages are consigned for disposal. Typically, RWMD looks to ensure periodic reviews are undertaken at ten-yearly intervals so that the Final stage LoC remains up to date and consistent with potentially evolving safety and environmental assessments. The result of a periodic review would be the production of an up to date disposability case within an Assessment Report and, if it is concluded that there are no new compliance gaps, this would allow re-issue of the LoCs.

In 1990, Nirex provided the first endorsement for packaging swarf[1] at the Sellafield Magnox Encapsulation Plant (MEP), arising from the de-canning of Magnox fuel at the Fuel Handling Plant (FHP). A separate endorsement followed in 1991 covering the methods to be used to determine the radionuclide inventory of these packages. A further endorsement for packaging Rotary Skip Wash Debris (RSWD), a component of swarf sent to MEP for packaging, was provided in 1994. Endorsements for packaging Magnox swarf retrieved from Magnox Swarf Storage Silo (MSSS) Compartments 19-22 and for the associated radionuclide recording system were provided in 1993. In 1995, packaging of Tokai Mura End Crops (TMEC) in MEP was also endorsed. However, the TMEC waste remains in the FHP pond, and it is understood that packaging through MEP is no longer the Sellafield Ltd reference process for this waste. Following agreement with Sellafield Ltd staff, this LoC will be withdrawn and has thus not been addressed in detail in this periodic review.

At the time of the first LoC for MEP waste packages it was recognised that there remained uncertainties in the evolution of the MEP wasteform and the LoC was caveated with the qualification that additional packaging measures, for example overpacking, might be required to compensate in the event of wasteform degradation.

Waste Processing and Packaging Process

On receipt at the FHP de-canners, Magnox fuel elements are end-cropped and then de-canned by pushing them through a slitter head assembly to separate most of the uranium metal fuel from the Magnox can. Separated fuel is routed for loading into a fuel magazine and dispatch to the fuel dissolver. The separated can comprising swarf, end fittings, Nimonic springs, sintox discs and uranium fuel carryover; is cumulatively referred to as swarf. The uranium carryover typically takes the form of small smears, slivers and chips but also sometimes arises as bulk uranium in the form of broken bar, with or without Magnox cladding intact. End-crops from all reactors except Tokai Mura are sentenced to FHP with the swarf, and generally contain no uranium.

Operators visually inspect the swarf material on a sort tray in order to identify and remove bulk uranium. The swarf tray is monitored using high resolution gamma spectrometry and provides the record inventory for the tray, which ultimately becomes part of the MEP waste package inventory record. It is not always easy for the operator to identify small pieces of bulk uranium amongst the swarf on the sort tray, and there is a limit on the size of items that can be picked up using manipulators. Where a fuel element has broken with cladding intact, any large pieces of clad uranium larger than approximately 200 mm (~2kg) are returned to the de-canner, where RWMD presumes the cladding would be successfully removed. Pieces of clad uranium smaller than this were historically sentenced to MEP with the swarf, but from 2007 operators at FHP

[1] The ‘decanning’ operation (i.e. removal of the Magnox metal can to expose the uranium fuel rod) is achieved by mechanical means. The stripped-away Magnox metal is referred to as swarf.

have been instructed to also separate clad bulk uranium where it can be removed by manipulator and stored at FHP. In due course, a treatment and disposal route will be developed for these fragments.

Once all possible uranium has been removed and the final inventory assessment made, the swarf is tipped into a swarf bin and dispatched to MEP for the waste packaging process.

It should be noted that FHP has been operational since 1985, although the waste packaging plant, MEP, did not become operational until 1990. In those intervening years the Magnox swarf from de-canning operations was tipped to Compartments 19-22 of the MSSS awaiting future retrieval and packaging. Between 1993 and 2000 the stored swarf was recovered from MSSS Compartments 19-22 and placed into swarf bins for transfer to and packaging in MEP. The wastes were retrieved by grab from the Compartments. Each grab of waste was weighed and then simply checked using a gamma dose monitor to ensure that the dose did not exceed prescribed limits.

At MEP the contents of the swarf bin, the waste and its cover water, are tipped into a 500 litre drum via a chute system. The 500 litre drum is vibrated to achieve the necessary packing density and level out the surface of the swarf. An Anti-Flotation Plate (AFP) is fitted to the filled waste container. Cover water is removed, using an ejector suction leg inserted into a de-watering tube engineered into each 500 litre container. The package is vibrated during de-watering to encourage water removal from swarf. The water carries fine particles of swarf components, potentially including fuel fines, which are stored at MEP in a fines tank and historically were periodically added back to some MEP waste packages. RWMD understands that this system does not now operate and thus fines are accumulated at MEP.

A pre-mixed grout is pumped into the container which is being vibrated, until a set level is achieved. After curing, a capping grout is added, the lid bolted down, and the container is decontaminated using high pressure water spays and the surface monitored for non-fixed contamination. The completed waste packages are loaded into stillages and transferred to the Encapsulated Product Stores (EPS1&2) awaiting provision of a Geological Disposal Facility (GDF). A total of approximately 18,000 packages were produced up to 2008, and further 4000 are expected to be produced to the end of Magnox operations.

Package Inspections

Development work studying the corrosion of encapsulated uranium observed unexpectedly rapid corrosion and localised expansion around pieces of uranium. As a result of findings of this development work, a programme of inspections was undertaken for MEP waste packages. Due to the early stage of those inspections, lack of dedicated inspection facilities and the large size of the waste stream, less than 0.2% of MEP packages have been inspected so far.

In April and May 2007 during the visual inspection of twelve MEP drums it was observed that two packages exhibited surface features, or bulges. As a result of the development work on the corrosion of encapsulated uranium, it was speculated that these features might have resulted from the expansive corrosion of uranium just below the container surface to form pockets of uranium corrosion products.

The two packages and specific others were retrieved again in September 2008 for inspection using RadScan equipment in order to determine whether the features were coincident with enhancements of gamma activity which may indicate the presence of bulk irradiated uranium fuel. From scanning for Cs-137 activity, a strong correlation between features and activity was found for features on the side of the packages and for some features observed on the base of the packages. At least four packages, and perhaps five or six, appeared to show a direct correlation between features and the presence of a region of high Cs-137 activity. This strongly indicated that uranium corrosion is a key factor in the cause of such features. There were also various areas of high Cs-137 activity on all drums monitored which had no corresponding surface protrusion. Possible reasons for these cases were speculated to include the possibility of uncorroded fuel and perhaps near container boundary accumulations of more dispersed fuel derived pieces, such as fines. These may, for example, have accumulated on the base near the de-watering tube, but do not form a source of bulk uranium metal.

Further inspections of additional packages in September 2009 have not identified surface features on those packages. RWMD believes that further inspections will occur and understands that Sellafield Ltd is investigating the potential to introduce new inspection techniques, such as laser profilometry to measure package dimensions and detect progressive changes and features.

Assessment Findings

The understanding of the fundamentals of uranium corrosion is improving but is still incomplete. The corrosion rate of uranium varies greatly, depending on the availability of oxygen, with rapid corrosion predicted under anaerobic conditions but very slow corrosion under aerobic conditions. Existing modelling and development work by Sellafield Ltd suggests it may be feasible for some of these features to lead to breaches of the waste containers, over timescales that may not be predictable. The uranium features observed in the containers represent relatively high localised sources of activity, and thus a potential challenge to safety cases and operating plans.

Even though modelling of the evolution of packages suggests breaches of the packages would be possible, simplifications in the modelling suggest current predictions may not be accurate. No breaches to the containment have been observed, and based on store operating conditions Sellafield Ltd believe there has been no loss of containment by the any of the stored packages. To be prudent, the periodic review has assessed the possible effects on GDF safety and operability of breaches in waste package containment, caused by the on-going corrosion and expansion of those pieces of bulk uranium immediately adjacent to the container walls.

The ‘as-made’ packages are expected to meet all requirements for both transport and GDF operations until backfilling, and therefore the assessment has concluded that in many respects the packages from MEP meet the RWMD Waste Package Specification and are expected to meet most disposal requirements as currently foreseen. However, the observed and potential effects of ageing of these packages, has led to uncertainties. These stem from the observation of unexpectedly rapid corrosion of uranium, and unresolved uncertainties over the rate of Magnox corrosion and its consequences.

MEP package records have also been reviewed in terms of content, physical format and long-term storage arrangements against current guidance. This follows a number of recent audits, which have identified weaknesses in this area. Sellafield Ltd has provided some limited further information that demonstrates that there is knowledge of where relevant records currently exist within Sellafield Ltd and that records management plans are being put into place. However, it is still not clear that MEP package records are being reviewed and the necessary information accumulated and compiled as a lifetime record for MEP waste packages.

A disposability assessment has been prepared, taking account of the identified uncertainties in waste package ageing and behaviour. The uncertainties all relate to the potential effects of corrosion of uranium and Magnox metals, which could cause dimensional changes in the wasteforms and containers, and generate heat and gases. The uncertainties identified in the assessment fall into the following technical areas:

- Potential for breaches in waste containers during normal conditions of transport;
- Potential for breaches in waste containers during GDF operations;
- Uncertainties in package performance due to the effects of Magnox corrosion on wasteform properties during a period of extended underground operations;
- Uncertainties in the rate of corrosion of Magnox, and the resultant effects of heat and bulk gas release during repository backfilling;
- Uncertainties over the fate of C-14 from irradiated Magnox and uranium and the implications for post-closure safety should C-14 be released in gaseous methane form.

Each of these areas is addressed in more detail below.

Uranium Corrosion and Transport

Under normal conditions of transport the IAEA Transport Regulations specify an activity release limit of 10^{-6} A_2 per hour for a Type B transport package (a flask containing the waste packages). It is currently assumed that the internal surfaces of the flask, the Standard Waste Transport Container (SWTC), will only be contaminated up to the acceptable levels specified for waste packages. MEP container failures, which might be caused by uranium features, could result in these levels being greatly exceeded. However, the Contents Specification for the SWTC would appear to provide a significant margin before the 10^{-6} A_2 limit was challenged.

The potential operability issues raised by internal contamination of SWTCs would also need to be addressed before it would be possible to confirm the tolerability of MEP packages with potential for containment failures. This issue appears potentially resolvable with further work. It should be noted that the assessed accident performance of the transport package containing MEP waste packages is not unacceptably affected by the uranium features, in part due to the IAEA limit on releases from the transport package of 1 A_2 per week after a transport accident.

Uranium Corrosion and GDF Operability

RWMD specifies that waste packages should be designed so that they can meet the requirements for handling and transport after 150 years interim surface storage and be capable of maintaining integrity for a further 50 years of operations in the GDF. Specifications also require waste package designers to design packages with a target of 500 years for container integrity. These time periods may be challenged by the corrosion of the embedded metals. If it is identified that waste package properties may be affected by ageing, such that specified requirements may not be met during GDF operations then further waste management measures may need to be developed and implemented.

One of the specified requirements relates to the performance of the waste package in impact accidents at the GDF. Impact accidents may release dispersible and respirable particulates from packages, depending on the severity of the accident and the condition of the aged waste package. MEP waste packages have relatively thin walled containers, and performance in accidents is partly dependent on the condition of the wasteform. Ageing of the wasteform may generate additional particulates, for example due to corrosion of bulk uranium or breakup of the grout wasteform due to more generalised corrosion of the waste metals, and thus increase the potential release. The Repository Operational Safety Assessment (ROSA) toolkit has been used to assess the consequences of Design Basis Accidents (DBA) involving MEP waste packages. The release fractions assessed were based on the performance of ‘as-made’ packages and a separate release fraction has been derived for a containment breach at a uranium feature.

It seems likely that releases from uranium features would be of greatest concern to the safety case, since this would be a new fault which might have a relatively high or more uncertain frequency compared to other faults. The assessment of operational safety for the GDF includes both deterministic (design basis accident (DBA)) and probabilistic elements. Numerical targets for DBA have been specified in the 2006 update to the Health and Safety Executive Safety Assessment Principles (SAPs) for nuclear facilities. The 2006 update introduced new basic safety levels (BSL) and basic safety objectives (BSO) and also provide a tiered approach to optimising the design/operation of the nuclear facility, depending on the expected frequency of the relevant initiating fault (or DBA). At this stage in the development of the repository design, indicative information on the frequency of the various design basis accident fault sequences is not available. Consequently, for the purposes of this assessment, a frequency for the most severe accidents is assumed. However, this frequency is not intended to apply to losses of containment caused by uranium features, although in mitigation the release from a containment breach at the site of a uranium protrusion might be much lower than from a breach caused by a more energy intensive impact accident.

Further work is required to improve the understanding of the likelihood and frequency of features leading to a loss of containment, and work to improve the knowledge of the potential RF and the dispersibility of the material released. The operational safety assessment would need to be re-visited to consider a containment loss as a new fault.

Magnox Corrosion and GDF Operability

In terms of Magnox corrosion, the R&D supporting MEP predicted that wasteform expansion due to Magnox corrosion during storage may be sufficient to cause cracking in the wasteform within the operational period. It should be noted that some degradation of the wasteform may not necessarily result in a failure to meet disposability requirements, since absence of cracking is not a specified requirement. It may however have some effect on immobilisation and the resulting accident performance of the package, for which more robust data is likely to be required.

It should be noted that the timescales estimated for Magnox to reach the extent of corrosion that is observed to cause some wasteform degradation in accelerated tests are calculated on an assumed chronic rate of corrosion of Magnox. This assumes that the chronic rate of corrosion is fixed, and does not further decrease below the rates measured in short timescale experiments. In practice, based on an understanding of the mechanism of Magnox corrosion, the gradual accumulation of corrosion products on Magnox metal might be expected to continually reduce the corrosion rate.

There is currently insufficient information available to estimate how compliance with relevant criteria will be affected. Further work by Sellafield Ltd and RWMD will be required to improve the data on Magnox corrosion, and then to understand how ageing may affect accident RF's and Waste Package Specification criteria.

<u>Heat and Gas Generation</u>

The rate of Magnox corrosion in grout-based wasteforms is believed to be very sensitive to temperature. The maximum temperature specified for the GDF vault backfilling operation is 80°C, although this temperature may not be reached in practice depending on the backfilling regime. Application of a maximum temperature of 80°C, combined with relatively poorly substantiated data on the rate of corrosion of cemented Magnox at this temperature, has resulted in an estimated rate of hydrogen production that is an order of magnitude higher than the limit specified by the Waste Package Specification. This limit was specified for transport conditions, which are not expected to reach 80°C.

Gas evolution would also be accompanied by heat from the corrosion reaction. Historical work from 1991 suggested that heat from Magnox corrosion could dominate all other sources of heat for a few years after backfilling at temperatures above 50°C. Other subsequent work argued that water availability in the grout would progressively reduce the corrosion rate. This needs to be resolved.

Further work is required by RWMD to understand the rate of corrosion of cemented Magnox at backfilling temperatures and how that evolves. Additional work is underway to understand how backfill temperature may be influenced by the backfilling regime and the Magnox corrosion, but is not yet complete. It may be necessary to control the rate of backfilling at a GDF to control temperature and limit the rate of heat and gas production.

<u>Carbon-14</u>

Gases containing C-14 may be generated through the degradation of activated waste materials in an aqueous environment, in this case through corrosion of irradiated metals in a cement pore solution. Reaction between carbonaceous species, such as carbide inclusions in metals, and water may result in the formation of simple gaseous compounds such as carbon dioxide (CO_2), methane (CH_4) and acetylene (C_2H_2), or small organic molecules such as formaldehyde and acetic acid. Of these potential products, unreactive gases such as methane and acetylene are of particular interest as, unlike carbon dioxide, they are unlikely to be retarded by reactions with cementitious materials during migration through a disposal facility.

In the case of MEP wastes there is the possibility that corrosion of the irradiated Magnox and/or uranium metals could generate C-14 in the form of methane, acetylene or other small organic molecules. The significance of C-14 in gas is being addressed in a coordinated generic research programme, much being undertaken by RWMD. The ongoing programme of research on C-14, includes work to assess the extent to which gas would dissolve in groundwater; work to assess the extent to which different geological environments have the potential to retard gas migration; and work to reduce uncertainties in the rates and quantities of gaseous C-14 generated. This issue is not unique to MEP waste packages and the outcome of the ongoing RWMD research programme is likely to be required to resolve this issue, unless new work to reduce uncertainties in the C-14 source-term is in itself sufficient. It is recommended that further work is undertaken by RWMD and Sellafield Ltd to understand the source term for C-14 as methane from corrosion of irradiated Magnox and uranium. It is feasible that even though some C-14 in the form of methane may be generated during metal corrosion, the source term in this form may only incorporate a fraction of the C-14 available.

Forward Strategy

This Assessment Report sets out the results of the periodic review bringing together the assessment of disposability as presently understood. As described in the previous section there remain gaps in the understanding which need to be closed out before an updated LoC can be issued. The LoC caveat which accompanied the original 1990 LoC was adopted in the light of the uncertainty over how repository environmental conditions would affect evolution of the packages. The option of overpacking to compensate for a deficiency in package performance remains relevant following this review, but needs to be underpinned by realistic strategies.

For future waste packaging at MEP, RWMD recommends that Sellafield Ltd should continue to avoid packaging of bulk uranium with swarf. Also, RWMD, Sellafield Ltd and regulators should consider the option of design measures to improve the packaging so as to avoid creating further packages with uranium features. RWMD suggests that a basket could be fitted inside MEP containers to reduce the proximity of fuel to the container walls.

For waste packages already in store it is recommended that additional measures (e.g. overpacking) are developed to a concept design level that could be applied to MEP waste packages prior to export to a GDF. The objective of the measures should be to compensate for potentially adverse behaviour of uranium features and long-term degraded wasteforms impacting transport and GDF operations.

Sellafield Ltd and RWMD need to address the likely frequency of failures, release fraction, form and dispersibility of radionuclides from a uranium

protrusion, addressing containment breach through drum-thinning and impact driven failures. Sellafield Ltd also need to revisit and review data on Magnox corrosion to agree a dataset, address whether chronic corrosion rate is fixed or continuously declining, and revise predictions of wasteform physical integrity.
Sellafield Ltd should continue to monitor waste packages and to improve monitoring techniques, such as the application of laser profilometry. Sellafield Ltd should use these data to validate predictions.
RWMD should complete further R&D to better understand how Magnox corrosion rate for conditioned Magnox varies with backfill temperature, and combine this information with a realistic prediction of disposal vault thermal evolution during and after backfilling. RWMD also needs to update the predictions of gas evolution, and confirm its acceptability or otherwise, and needs to complete its generic research into the fate of C-14 in the gas phase from a geological disposal facility. Sellafield Ltd and RWMD should cooperate to develop a dataset on the source-term of C-14 from corrosion of irradiated Magnox and uranium.

Conclusions

A periodic review of the LoC for MEP waste packages has been undertaken. The assessment has concluded that in many respects the packages from MEP meet the RWMD Waste Package Specification and are expected to meet most disposal requirements as currently foreseen. The ‘as-made’ packages are expected to meet all requirements for both transport and GDF operations until backfilling. A disposability assessment has been compiled although at this stage is not yet complete since five areas of uncertainty have been identified where further interactions between Sellafield Ltd and RWMD are required. The uncertainties stem from the reported surface features on some drums and the interpretation that this is due to unexpected corrosion of uranium metal. Unresolved uncertainties over the rate of Magnox metal corrosion also lead to uncertainties in wasteform performance.

A range of activities have been identified for addressing the uncertainties. These are communicated to Sellafield Ltd in this Assessment Report. Issue of an updated Letter of Compliance for MEP waste packages will be contingent upon successfully addressing the five areas of uncertainty.

MEP package records have also been reviewed in terms of content, physical format and long-term storage arrangements against current guidance. However, it is not clear that MEP package records are being accumulated and compiled as a lifetime record for MEP waste packages. Work needs to be prioritised in this area to reduce the risk of loss and to ensure all necessary information can be identified and retrieved in the future.