Radioactive Waste Management

AWE Legacy Hydrodynamic Vessels (Interim Stage)

Summary of Assessment Report

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Background

Radioactive Waste Management Limited (hereafter RWM) has undertaken an Interim stage Disposability Assessment for the proposals by AWE for the packaging of legacy hydrodynamic (HD) vessels that are generated to underpin the performance of the UK's nuclear deterrent.

AWE has proposed to package the legacy HD vessels by encapsulation within stainless steel $3m^3$ boxes.

The objectives of this Interim stage assessment of proposals for packages containing legacy HD vessels are to provide AWE with:

- An assessment of disposability in accordance with the Joint Regulators' Guidance to Industry
- Supporting advice on disposability of legacy HD vessels to AWE in the form of an Assessment Report
- Where appropriate, endorsement of the proposals via issue of a Letter of Compliance (LoC).

Further information on the Disposability Assessment process is available elsewhere[1].

AWE has been interacting with RWM (and its predecessors) on the disposability of HD vessels since 2007, the early focus being on the 'Hydrus' HD vessel. Interactions on the disposability of historic ("legacy") HD vessels have taken place since 2009, when AWE submitted Conceptual stage packaging proposals based on the process of packaging inside $3m^3$ boxes. This culminated in Conceptual stage endorsement of the proposals in 2010.

Since 2010, AWE has been refining its proposals for the legacy HD vessels into a higher level of detail in response to the Action Points raised by RWM in 2010. This culminated in an Interim stage submission by AWE in April 2015 to close out the outstanding issues and to assemble the new information into an update of the disposability case, the findings from which are set out in this Assessment Report.

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 Geological Disposal Facility (GDF) derived from the generic Disposal System Safety Case (DSSC).

[1] NDA, *Waste Package Specification and Guidance Documentation: WPS/650 Guide to the Letter of Compliance Assessment Process*, WPS/650/02, March 2008

The general requirements placed on waste packages for disposal in a GDF are embodied in the Generic Waste Package Specification (GWPS)[2]. Further requirements for particular types of waste package are embodied in the relevant Waste Package Specification (WPS). In the case of the AWE legacy HD vessel waste packages, the relevant WPS is that for packages based on the corner lifting variant of $3m^3$ box.

Scope of the Assessment

To date, twenty vessels have been generated since the HD test facility was commissioned in the 1960s. Four further vessels are expected to be generated to make a total of twenty-four vessels, all of which are classified as ILW. These are collectively referred to as 'legacy' HD vessels to distinguish them from the next generation successor vessel that is currently under development.

AWE HD vessels are identified in the UK RWI as waste stream 7A40, although this encompasses both legacy and Hydrus HD vessels.

Packaging Process

Nature of the Waste

AWE performs HD experiments to test the performance of materials subject to explosive shock using high explosives. Since these experiments involve the use of radioactive materials, they are performed inside sealed vessels. Given the extreme conditions of temperature and pressure generated in the tests, the vessels are constructed from thick boiler-plate or submarine-grade steels to provide a highly robust containment system. This robustness is reflected in the pressure ratings of the vessels, which range from 150 to 350 bar. The atmosphere in the vessels is purged after the test prior to the vessels being sealed for long-term storage and eventual disposal.

The HD experiments were performed in the HD vessels using a range of materials including wood, plastics, glass, explosives, cemented blocks and small quantities of radioactive material. In the post-experimental state, the vessel contents are largely oxidised and widely dispersed throughout the vessel with all explosive material is used up in the test. The vessels rely on thick steel walls and multiple high integrity seals to ensure an exceptional degree of containment of these materials. The nature of these sealing arrangements ensures that there is no external contamination, enabling the vessels to be contact-handled at AWE.

Waste Processing and Packaging

The packaging proposals being developed by AWE are based on encapsulation of the vessels in cement within stainless steel $3m^3$ boxes. Although the vessels would be grouted into the boxes using cement, there is no proposal to open the vessels themselves to encapsulate the contents; the waste inside the vessels would therefore remain in its post-experimental state, with all of the vessel ports remaining fully sealed but containing a void.

AWE has made ALARP and BAT arguments for not breaking the containment offered by the HD vessels in support of its packaging proposals. Breaking the containment offered by the vessels would expose workers to a significant radiological and chemical hazard. Introduction of an encapsulant would also necessitate modification of the vessel to allow for ventilation of gases that could be generated as a consequence of the interaction between the encapsulant and the vessel contents.

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

AWE has adopted a square-cornered $3m^3$ box container design as the basis for the HD vessel waste package. This container is based on a design originally conceived by Sellafield Ltd, and which has been subject to separate technical evaluation and endorsement by RWM. AWE has developed this container design further to include an internal cradle to secure each vessel into a fixed orientation prior to grouting. Each box would contain a single HD vessel, with the cradle design being developed to account for the small design variations that exist between the 24 legacy vessels.

The empty $3m^3$ box would be located on its side to facilitate loading of the cradle/vessel assembly. The cradle design includes small rollers that would be used to slide the cradle/vessel assembly into the box. Once in position, the cradle would be locked into position using mechanical catches. The box would then be tipped through 90˚ on to its base using a hydraulic tipper, from where it would be moved to a grouting station.

With the $3m^3$ box in an upright position, the interspace between the box wall and vessel would be infilled with a cementitious grout. Boxes would be filled as far as possible to minimise ullage. The grout would then be allowed to cure before the lid is fitted to the box using a series of bolts.

The finished waste packages would initially be stored within the existing process facility at AWE's Aldermaston site. The proposals for temporary storage of the finished HD waste packages are based around the use of a tented enclosure around the packages within the process building to allow for control of local environmental conditions. AWE has committed to transfer of the HD waste packages to the purpose-built on-site ILW store when it becomes available. AWE is currently developing its overall strategy for higher activity waste management, an important component of which is the development of this dedicated storage facility for all of its finished ILW packages.

Assessment Inventory and Number of Packages

Each HD vessel was configured to perform a unique experiment with different material components being loaded into the vessels for each test. The nature of these experiments means that reliable records are available for the majority of the vessels. There is some uncertainty over the inventory information in the very first seven HD vessels but radiometric measurement and other available evidence have been used to compile information regarding their properties to give sufficient confidence that their properties are bound by the characteristics of the later vessels, for which accurate data is available.

The proposals would generate a total of 24 off $3m^3$ box waste packages.

Assessment of Disposability

Waste Package Properties and Performance

RWM considers that the 'as manufactured' AWE legacy HD vessel waste packages are likely to perform adequately in the context of mechanical and physical properties. The high integrity of the vessels would fulfil all of the radionuclide containment functions required to ensure safe handling, storage, transport and disposal.

The vessel contents are largely benign, yet the potential for ongoing metal corrosion is recognised. Corrosion mechanisms are however limited by the low availability of both water and oxygen. The thickness of the vessel walls is sufficient to ensure that through-wall corrosion would be credible on periods extending to thousands of years. Further protection would be provided by enclosure within the $3m^3$ box and surrounding cement grout.

The generation of gases within the HD vessels is recognised as a consequence of metal corrosion and radiolysis of water and organic species. The hermetically sealed nature of the vessels means that an over-pressure could develop over extended timescales. The potential magnitude of such an over-pressure is trivial compared to the design capacity of the HD vessels, which are designed to withstand transient extremes of pressure and temperature. The RWM assessment has shown that the AWE packages containing potentially pressurised HD vessels can be safely handled and disposed of on account of the design of the HD vessels and overall waste package.

Detailed analysis has been undertaken to establish the likely performance of the AWE HD vessel waste packages to credible accident conditions such as exposure to fire, drops from height or other waste packages impacting onto the AWE packages.

For waste packages exposed to a fire accident, the thick layer of cement grout surrounding the vessels would provide a very high degree of thermal insulation, such that the temperature rise experienced by the vessel itself would be trivial.

Impact accident modelling was undertaken using finite elements models that had been validated against real drop testing of the Sellafield Ltd designed $3m^3$ box. These models were enhanced to include the additional design features of the AWE HD vessel waste packages. For the HD vessel waste packages dropped from the most limiting height of 15m, the modelling compellingly demonstrated that there would be insufficient damage to result in any loss of radionuclide containment provided by the HD vessel. This can be largely credited to the massive construction of these vessels, which have been designed to withstand an explosive blast, with additional protection being offered by the surrounding cement grout and stainless steel $3m^3$ box.

For the package-on-package/aggressive feature impact accident scenario, the finite element modelling initially showed more variable results. The aggressive feature impact was taken to be another square-cornered $3m^3$ box being dropped from a height of 10m corner-first onto the lid of the AWE package. For the package containing the later more heavily constructed design of HD vessel (known as the V3 and V4 variants), the results were positive, with no loss of containment damage being inflicted onto the vessels, despite using conservative assumptions throughout. However, the results for the earlier thinner-walled designs of HD vessel (known as the V1 and V2) suggested that a breach in the vessel wall could be possible in the most limiting circumstances. For this reason, AWE re-visited the design of the waste package to explore various means to enhance protection of the V1 (and latterly the V2) vessel. The final design that was adopted was based around a 30mm thick armoured plate that would fit under the lid and above the vessel. The modelling results when this feature was included provided a satisfactory demonstration that the V1 and V2 vessels would be adequately protected in the event of the most limiting aggressive feature impact.

It was concluded that the AWE HD vessel waste packages would fulfil RWM requirements under all credible accident conditions, with package radionuclide release fractions of zero being adopted for use in the transport and operational safety assessments.

The mass of radioactive materials present in each of the vessels is known very precisely due to the nature of the hydrodynamic experiments. The HD vessel waste packages do not fit within any of the existing generic waste package criticality safety cases due to the nature of the wasteform and so AWE has developed a package-specific Criticality Safety Assessment (CSA) with support from RWM. This covers normal and accident conditions for transport, operations and post-closure. The CSA uses detailed calculations to justify a package Safe Fissile Mass (SFM) that is well

above the known fissile content of any single legacy HD vessel. For the transport and operational safety scenarios, this SFM is based on full flooding of the vessels by water (as might occur in an extreme, yet arguably incredible, accident situation). For the post-closure phase, the SFM was derived based on the long-term evolution of a stack of seven AWE packages collapsing to generate a slab of fissile material distributed in groundwater. The package specific CSA provided a robust demonstration that a criticality safety case could be made for these waste packages.

Compliance with the Transport System Design and Safety Case

The dose rates for the AWE waste packages will be low and transport accident situations would not lead to any loss of radionuclides from the waste packages. However, the carriage of potentially pressurised items means that additional measures need to be put in place to support the transport safety case. This is because the deterministic approach to the transport safety assessment requires that consideration is given to all potential sources of gas generation from the waste packages. While the engineering design supports the case that off-gassing from the sealed HD vessel would not be credible during the transport phase, the consequences must nevertheless be evaluated.

The transport safety assessment was carried out on the basis that the pressure inside the hydrodynamic vessels could be discharged during the transport phase, such that it is released into the cavity of the SWTC, which itself becomes pressurised with the gas from the vessel. The key requirement for compliance with the IAEA transport safety regulations is that the pressure inside the cavity of the transport flask (the Maximum Normal Operating Pressure, MNOP) shall not be exceeded. RWM has developed the SWTC with a defined MNOP of 7 bar(g). An analysis by RWM has established that the SWTC-150 would comply with this requirement for the AWE hydrodynamic vessel packages owing to the larger cavity of this flask relative to that of the SWTC-70 or SWTC-285.

A further consequence of gas release from the HD vessel is the potential for flammable atmosphere formation due to the expectation that the atmosphere within the vessels would comprise mainly of hydrogen. Oxygen gas would not be present within the vessels since any oxygen generated, for example by radiolysis of moisture, would be expected to be consumed in metal corrosion processes. The cavity of the transport container would also need to be purged with inert gas prior to the start of the transport phase to eliminate any oxygen that would otherwise exist in the cavity to eliminate the potential for flammable atmosphere formation.

RWM considers that the package-specific CSA developed by AWE for the transport phase is robust and offers a pragmatic, yet sufficiently pessimistic treatment of the proposed packages. Nevertheless, it is also recognised that the approach is not fully deterministic and for this reason, the case may not be entirely consistent with the IAEA transport safety regulations. This is because a fully deterministic criticality case relies on optimisation of all parameters to provide a fully pessimistic treatment of criticality safety. However, the geometric configuration of the waste inside the vessel is not known and AWE has adopted a realistic, albeit still conservative, representation of the vessel contents in its CSA calculations. This issue is not unique to the AWE HD vessel waste packages since it applies to many other types of waste package. RWM recognises the challenges with complying with this aspect of the transport regulations and is making efforts to develop a solution that would be agreeable to the UK transport regulator. RWM will endeavour to keep AWE updated on this matter as the interactions with the transport regulator develop.

In summary, RWM believes that the 3m^3 boxes containing legacy HD vessels would be compliant with the transport system design and safety case as currently foreseen provided that the SWTC-150 transport container is used, that the atmosphere in the

cavity of this transport container is inerted to control the generation of a flammable atmosphere and the package-specific criticality safety case for the transport phase is found to be acceptable to the transport regulator.

Compliance with Engineering Design and the Operational Safety Case

The proposed waste packages have been assessed against the operational safety aspects of the WPS for 3m³ boxes and directly against the requirements of the deterministic operational safety case established in the generic DSSC.

RWM considers that the legacy HD vessels in 3m³ box waste packages would be compliant with the disposal system engineering design as currently foreseen. This is again attributed to the low external dose rate and radionuclide containment offered by these packages.

The probability and consequences of hydrogen release from the AWE packages is deemed to be low and therefore the additional conventional risk from handling these potentially pressurised packages during the operational phase would be acceptable.

Overall, RWM considers that the waste packages would be compliant with the disposal system Operational Safety Case as it is to be developed.

Compliance with the Environmental Safety Case

The proposed waste packages have been assessed against the environmental safety aspects of the WPS for 3m³ boxes, and directly against the requirements of the environmental safety case established in the generic DSSC.

The small number of packages and low radionuclide content of the vessels means that this waste stream would not make a significant contribution to the total risk in the groundwater pathway.

At some stage during the post-closure phase, the bulk gas generated within the vessel would be released, most likely as result of general corrosion of the vessel after an extended timescale in a saturated environment. Such a release may occur on a gradual basis as vessel seals age or more acutely as a consequence of through-wall corrosion. In either case, the impact of bulk gas release is not considered to be significant due to the hydrostatic pressure that would exist in a GDF at depth in the post-closure phase and the relatively small volume of gas involved when taken in the context of the gas that would be generated from corrosion of many hundreds of adjacent waste packages.

RWM considers that the AWE legacy HD vessels in 3 m³ box waste packages are compliant with the disposal system environmental safety requirements as currently foreseen, based on their compliance with the generic Operational Environmental Safety Assessment and the generic Post-Closure Safety Assessment.

Status of Management System and Data Recording

The current proposals would represent a first of a kind for packaging higher activity wastes by AWE. Accordingly, AWE is only just beginning to establish its company management system arrangements for higher activity waste packaging, including management of waste package records and storage of finished products. Outline details of such a management system have been supplied but further development would be required to take the current packaging proposals beyond the Final stage assessment. Nevertheless, RWM is confident that AWE should be capable to implementing a system that would provide the necessary assurance that the packages would be manufactured to the required quality. Specific evidence will be sought that this is the case at the Final stage, when all such arrangements will need to be finalised. This will be accomplished through a future RWM-led technical audit of AWE's management system arrangements.

Detailed comments have been provided on the draft versions of AWE's key management system documents; these include the Waste Product Specification, Criticality Compliance Assurance Documentation and data recording methodology. It is expected that these documents would be updated for further review by RWM at the Final stage.

Conclusions of Assessment of Disposability

The proposed legacy HD vessel waste packages have been found to be consistent with RWM requirements and therefore may be considered to be disposable.

The review against the requirements of the relevant Waste Package Specification for the $3m^3$ box, WPS/315, indicates that there are a number of areas where further information is required to establish full compliance. In particular, AWE will need to provide a full set of approved container design drawings that include information on the design of the box vent and location of identifier. Nevertheless, sufficient evidence has been provided at the Interim stage to support endorsement, with a view to resolution of these issues at the Final stage.

Requirements for Further Work

The RWM assessment of the Interim stage submission has identified the principal technical issues that would need to be resolved to progress the proposals for packaging AWE legacy HD vessel wastes to the Final stage. The key areas for development of the proposals at the Final stage include:

- Finalisation of the $3m^3$ box container design and provide an agreed final set of drawings for review. There remain a number of minor design issues that also need to be clarified including the suitability of lid bolting arrangements, the specification of waste package identifiers and confirmation that the box dimensions would be fully consistent with WPS/315;
- Updating the principal management system documents controlling the packaging and storage of higher activity waste, as well as specific documents relating to the legacy HD vessels including the vessel characterisation report, the data recording methodology, the Waste Product Specification and Criticality Compliance Assurance Documentation; and
- Confirm the long-term safeguards status of the finished waste packages.

Conclusions

RWM has performed an Interim stage disposability assessment for $3m^3$ box waste packages containing legacy HD vessels from AWE. The assessment has considered the consistency of the proposed packages with RWM requirements for safe long-term management, including transport, emplacement and extended storage underground, and disposal, as currently expressed for the Illustrative Geological Disposal Concepts for Intermediate Level Waste and Low Level Waste. This also addresses compatibility with the Waste Package Specification for the corner-lifting variant of $3m^3$ box waste package, an essential component of which includes consideration of the effects of interim on-site storage of the conditioned waste at AWE's Aldermaston site.

It is concluded that the proposed waste packages are consistent with RWM requirements and therefore the packages may be endorsed at the Interim stage through the issue of a Interim stage Letter of Compliance. A formal assessment of disposability has been recorded that supports this conclusion.