UNDERSTANDING THERMAL CONSTRAINTS FOR HIGH-HEAT-GENERATING WASTES IN THE UK

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ABSTRACT

The UK has a range of high heat generating wastes including legacy spent fuel, vitrified HLW and potentially new build spent fuels that may require geological disposal.

The heat generated by legacy wastes and potential future wastes must be taken into account in the design of a UK Geological Disposal Facility. In the absence of a specific disposal site, RWM is developing generic disposal solutions for these wastes that take due account of high thermal loads in view of the uncertainties that are inherent in the absence of a specific site.

To facilitate planning decisions and hazard reduction, RWM operates the Disposability Assessment Process. This is used to provide advice to waste producing organisations on approaches to waste packaging and interim storage to ensure compatibility with future geological disposal requirements, whilst taking due account of uncertainty.

I. INTRODUCTION

The Nuclear Decommissioning Authority (NDA) is responsible for planning and implementing geological disposal in the UK and has established Radioactive Waste Management Limited (RWM) (a wholly owned subsidiary) for this purpose.

The inventory of higher activity radioactive wastes planned for geological disposal in the UK is defined in the White Paper on Implementing Geological Disposal[1]. The inventory of higher activity wastes may be broadly categorised into Low-Heat-Generating Waste (LHGW) or High-Heat-Generating Waste (HHGW) since the way that these two types of waste is managed for disposal is quite different. A summary of the potential inventory of higher activity wastes destined for geological disposal in the UK is provided in Table I.

TABLE I. Potential Inventory for Geological Disposal (HHGW is highlighted in **bold** font)

Waste category	Packaged volume (m^3)
High Level Waste (HLW)	**9,290**
Intermediate Level Waste (ILW)	456,000
Low Level Waste (LLW)	11,800
Spent Fuel	**66,100**
Plutonium	**620**
Uranium	112,000
Total	656,000

The geological environment for a UK Geological Disposal Facility (GDF) is not yet known. Three broad types of host rock, (higher strength crystalline rock, lower strength sedimentary rock and evaporites) are being considered to encompass possible geological environments, along with a range of possible disposal concepts in planning for disposal of the diversity of radioactive wastes.

Disposal concepts for LHGW are typically based around multiple containers stacked in vaults, backfilled using a cementitious backfill. The majority of UK LHGW is encapsulated using cement and packaged in thin-walled stainless steel containers. Many thousands of such packages have already been generated and are held in interim storage pending disposal.

HHGW typically comprises spent nuclear fuel and vitrified HLW and is assumed to be packaged in high integrity containers that would provide long-term radionuclide containment in a disposal environment. In a GDF, such containers would be physically separated using additional engineered barriers. Buffer materials would be placed around the packages to protect the container from corrosion and other degradation mechanisms.

Figures 1 and 2 illustrate generic disposal concepts for HHGW in higher strength crystalline rock and lower strength sedimentary rock respectively.

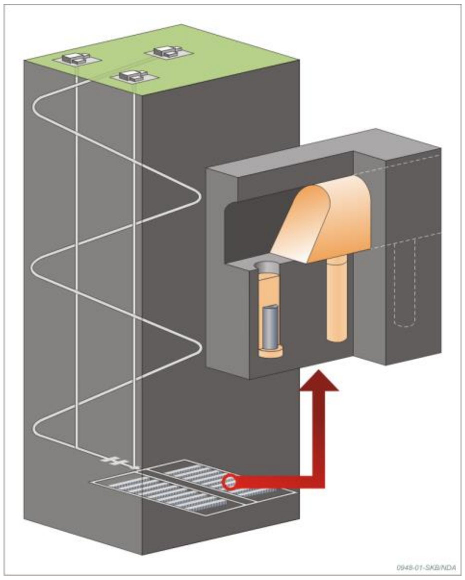

Figure 1 Generic disposal concept for HHGW in higher strength crystalline rock

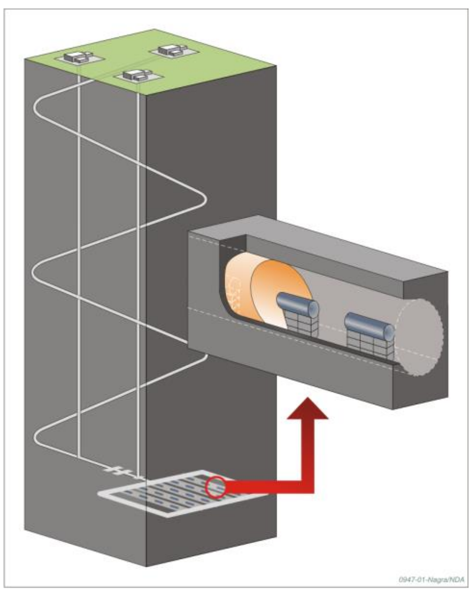

Figure 2 Generic disposal concept for HHGW in lower strength sedimentary rock

RWM is developing understanding of how the heat generated from the diverse inventory of HHGW could impact on engineered barrier systems. This paper goes on to describe how RWM develops an understanding of the nature of UK HHGW and how this information is used to develop GDF concept designs, understand waste packaging limitations and translate these needs into conditioning requirements.

II. UK INVENTORY OF HIGH-HEAT-GENERATING WASTES

The inventory of UK HHGW is both large in packaged volume and diverse in nature, and future arisings are also subject to some uncertainty. This section describes the major types of existing HHGW, as well as potential future arisings that may come forward for future geological disposal.

The UK has generated a significant stock of vitrified HLW from reprocessing of spent nuclear fuel since the 1950s. The existing reprocessing facilities are due to cease operating within the next decade and SF continues to arise from the UK's existing fleet of Advanced Gas-cooled Reactors (AGR) and the single LWR power station, Sizewell B.

Historical research and development and military propulsion programmes have also generated a range of so-called 'exotic' types of SF. Although exotic SF is small in volume, it is diverse in nature and includes fast reactor fuel and breeder material.

Civil spent fuel reprocessing in the UK has generated a stockpile of separated plutonium. NDA is currently developing credible options to underpin its strategy on plutonium dispositioning. One option under consideration is to re-use this material to fabricate MOX fuel for irradiation in a new reactor. This would generate MOX SF that may require geological disposal. An alternative option being considered is conversion into a ceramic product suitable for direct geological disposal. RWM is supporting NDA strategy development in this area by providing disposability advice on final wasteforms.

In addition to the 'legacy' wastes and nuclear materials described above, the UK is seeking to develop new nuclear generating capacity. The current planning assumption is that any SF generated from future new build power stations would be subject to interim on-site storage prior to geological disposal. Current plans indicate that up to 16GWe of additional generating capacity could be brought on line in the future.

III. UNDERSTANDING THERMAL CONSTRAINTS FOR GEOLOGICAL DISPOSAL

RWM has a long history of developing disposal concepts for LHGW. While much international experience has been generated on the development of disposal concepts for HHGW, UK disposal concepts for HHGW are less well established. The diversity and volume of UK HHGW also generates a number of technical uncertainties that need to be addressed to support future decision making and concept selection. For this reason, RWM has established a dedicated project to enhance understanding of the factors affecting geological disposal of high-heat generating wastes with a view to supporting the development of the disposal system specification (i.e. the disposal system requirements) and spent fuel life cycle options (e.g. supporting the development of storage and packaging solutions).

The project comprises a series of tasks that will develop understanding and create UK expertise in the geological disposal of high-heat generating wastes. These tasks are described in the project roadmap[2] and cover the following topics:

- Development of a better understanding of thermal constraints for different buffer materials, with a focus on swelling clays (e.g. bentonite);
- Exploration of the range of disposal parameters using a Thermal Dimensioning Tool (TDT), which allows optimised disposal scenarios to be explored for the three generic geological settings described above;
- Enhancing knowledge of the inventory for UK spent fuels and vitrified HLW to reduce uncertainty in the data being used in thermal modelling studies; and
- Concept engineering design work to examine the feasibility of the disposal concepts for high-heat-generating wastes. This aspect of the project also explores the development of novel UK container designs including Multi-Purpose Containers (MPCs) for interim storage, transport and disposal of spent fuel.

Radioactive waste management organisations around the world have developed many potential designs for geological disposal of higher activity wastes. Often these designs use cement, or swelling clay (e.g. bentonite), or both in the near-field. Bentonite is used because:

- It will swell, leading to closure of voids;
- The high swelling pressure will reduce microbial activity;
- It will have a very low permeability and therefore restrict water migration;
- It will trap and hence filter colloids; and
- It possesses good sorption properties to further limit radionuclide migration following canister degradation at very long timescales.

The use of bentonite has important implications for the management of high-heat generating wastes because it can undergo chemical alteration at significantly elevated temperatures which may adversely affect its swelling potential. For practical reasons several waste management organizations have suggested the thermal power of the array of canisters within a GDF therefore has to be managed so that the temperature stays below a limit of 100°C. Adoption of a thermal limit of 100°C has been identified as a constraining factor for some of the most thermally limiting spent fuels, for example new build spent fuel, and represents a challenge for waste disposal. There is therefore a need to fully understand the thermal thresholds in the range of disposal concepts being considered by RWM.

An initial step to developing such expertise in the UK is through collaboration with overseas organisations that are further advanced with research on bentonite buffer materials. For example, RWM is participating in the second phase of the Alternative Buffer Materials experiment at the Äspö underground research laboratory. This ongoing experiment is exposing a number of clays to a temperature of up to 130°C.

Thermal dimensioning studies are being undertaken to explore methods and approaches for mitigation of the heat generated by the inventory of UK HHGW in different disposal concepts. This will be achieved by varying the parameters affecting heat transfer, including waste package loading and spatial configurations of those packages. The early focus of the work will be to identify the thermal constraints on specific outline conceptual designs, building upon the findings of the work described above on the influence of heat on buffer materials. The constraints on the design will relate to important features of the engineered barrier system and parameters such as waste package loading, package dimensions and package spacing. The work will therefore identify an acceptable range of designs and parameters for waste package disposal concepts and layout of the GDF.

The TDT has been developed to support analyses of different combinations of package assumptions and other GDF factors, such as spacing of those packages and host rock properties, to assess the compliance with thermal limits.

In order to develop disposal concepts for HHGW, it is necessary to understand the engineering feasibility associated with construction and operability of such concepts. Design feasibility issues to be investigated include:

- Consideration of whether the heat from the spent fuel and HLW disposal areas could affect the temperature constraint of ILW vaults, recognising that the UK situation currently envisages a co-located facility for disposal of both ILW and high-heat generating wastes;
- Whether there are any implications for the emplacement of backfill materials around hot packages (e.g. drying of bentonite);
- Operational issues associated with handling and emplacement of larger packages,

particularly MPCs in different geological settings;

- Large vault construction, maintenance and ventilation for an extended operational period, and eventual backfilling. This is particularly relevant to the concept being considered for larger MPC type packages where a period of deferred backfilling may be desirable for the management of the higher thermal load that might be associated with these higher inventory packages.

The scope of work listed above (and described in detail in the project roadmap[2]) is anticipated to be completed during summer 2015. The information obtained will be used to support concept design and allow the development of waste packaging specifications for high-heat-generating wastes. This information will also be used to support the advice provided to waste producers through the Disposability Assessment Process on packaging and storage requirements for their heat generating wastes.

IV. DISPOSABILITY ASSESSMENT PROCESS AND ITS APPLICATION TO HHGW

RWM operates the Disposability Assessment Process by which waste producers' plans for waste packaging are assessed against the RWM packaging specifications[3] and the disposal system safety case[4]. The Disposability Assessment Process is embedded within the regulatory arrangements for packaging of radioactive waste in the UK [a].

The principal aim of the Disposability Assessment Process is to minimise the risk that the conditioning and packaging of radioactive wastes results in packages incompatible with geological disposal, as far as this is possible in advance of the availability of Waste Acceptance Criteria for a geological disposal facility. As such, it is an enabler for early hazard reduction on UK nuclear sites.

The Disposability Assessment Process has a long history, with the earliest formal advice and endorsement being issued in 1986. The process was originally developed primarily as a means to assist site operators to convert LHGW into safe and disposable forms. More recently, the process has been extended to cover packaging plans for HHGW, which is the subject of this paper.

The Disposability Assessment Process considers the performance and safety of waste packages during their transport to a GDF, handling and emplacement at that facility, and in the longer-term post-closure period. It also considers interim storage of waste packages prior to transport to a GDF. A 'disposable' waste package is one that has been shown to be compliant with the relevant packaging specification and the underlying needs for safe transport to and emplacement in a GDF.

Open engagement is an important part of the Disposability Assessment Process. To this end, RWM is keen to promote early, sustained and positive engagement with waste packagers, before the preparation of a formal submission and/or assessment of a packaging proposal at any stage of the Disposability Assessment Process. This is aimed at enabling early identification of key issues to reduce the number of iterations required during the assessment process and to achieve positive progress in hazard reduction.

One of the important considerations for HHGW is the impact of heat output on the engineered barrier systems within the different disposal concepts. For this reason, RWM assess whether packages containing HHGW have the potential to generate temperatures in excess of 100˚C in buffer materials at any time following the emplacement and backfilling of packages.

Thermal modelling tools, including the TDT referred to above, are routinely used to support disposability assessments for HHGW. This is used to estimate the cooling time that would be required to ensure compliance with the assumed 100˚C thermal limit in different geological settings and disposal concepts. The TDT also allows the design of the disposal concepts to be modified, for example in terms of the space between adjacent heat-generating packages, to reduce this cooling time. The TDT allows a meaningful analysis of uncertainty that is impacted by the thermal output of different waste types in a range of host rock settings. In this way, the TDT can be used to support the development of waste packaging solutions for new and novel types of HHGW, whilst taking due account of uncertainty.

The temperature evolution in the EBS around a waste container is a function of many variables; some of which can be adjusted by altering the design and emplacement schedule – for example the waste loading per container, the container separation distance or the emplacement time – and some of which are unalterable properties of the geological environment – for example the thermal conductivity, or the ambient temperature of the host rock.

The uncertainty in peak temperatures caused by uncertainty in the properties of the geological environment is substantial at a generic stage of siting, and might amount to an uncertainty in calculated peak temperatures of many tens of degrees Celsius, or it could

[a] An overview of the Disposability Assessment Process is available at http://www.nda.gov.uk/publication/wps65003-geological-disposal-an-overview-of-the-rwm-disposability-assessment-process/ (accessed 03 November 2014)

lead to a requirement for extended storage to allow the cooling necessary to satisfy temperature limits in a GDF. This uncertainty will be reduced as properties of a site become known and as a disposal concept is refined. However, it is necessary to make decisions and planning assumptions now which account for this uncertainty. The TDT can help understand the influence of uncertainty by analysing the effect of optimistic and pessimistic choices of parameters, as well as reference case values, on the temperature evolution. The TDT is therefore an important tool in the Disposability Assessment Process since it allows RWM to advise producers of HHGW on the requirements for packaging of their wastes. Some examples of how thermal modelling tools are used to support the Disposability Assessment Process are included in the following sections of this paper.

V. SUPPORTING THE GENERIC DESIGN ASSESSMENT PROCESS FOR NEW NUCLEAR BUILD

The Generic Design Assessment (GDA) process has been developed by UK regulators to evaluate proposals from the developers of potential new nuclear power stations. UK Government policy is that before development consents for new nuclear power stations are granted, the Government will need to be satisfied that effective arrangements exist or will exist to manage and dispose of the waste they will produce. RWM provides an input into the GDA process to meet this requirement by providing disposability advice on the wastes and SF that would be generated from such new nuclear stations.

Potential new nuclear power stations being considered for implementation in the UK include designs that use fuel assemblies that are dimensionally larger than those currently used in existing UK power stations. Furthermore, this fuel has the potential to be taken to greater burn-ups. Consequently, SF generated from new nuclear power stations has the potential to possess higher thermal outputs than legacy SF.

Thermal modelling is used to support the GDA process by evaluating the potential range of cooling times and packaging constraints for new build SF. This information is then used to explore the impact of including new nuclear generating capacity on the size and costs of a UK GDF.

Thermal analyses suggest that cooling periods for new build spent fuel could be reduced considerably by selective packaging of both long-cooled and short-cooled fuel assemblies in a common container[5]. The flexibility provided by the recently developed TDT is expected to take this a stage further by allowing much more detailed analyses of uncertainty to allow a robust understanding of the needs for interim storage and packaging.

VI. DEVELOPING CONCEPTS FOR SPENT FUEL

The thermal dimensioning studies completed within the disposability assessment process have identified that SF may need to be stored for several decades before it would be suitable for geological disposal. Part of the disposability assessment process is to evaluate proposals for long-term interim storage to ensure that SF and HLW will ultimately be suitable for disposal once a facility becomes available and/or the waste is sufficiently cool for packaging and disposal.

Plans are already being implemented for long-term storage of legacy SF and RWM is supporting feasibility studies to understand how stainless steel clad spent fuel from UK gas-cooled reactors is likely to evolve under both wet and dry storage conditions to support future decision making.

Limitations in wet storage capacity at the UK's only PWR at Sizewell B means that dry storage using Multi-purpose Containers (MPCs) is being implemented. Currently, a commercial design of MPC has been selected for this purpose, but this MPC may be too large for routine transport over the UK road and rail network to make it suitable for disposal at a GDF.

In recognition of the potential wider benefits of multi-purpose containers for SF, RWM is currently exploring the feasibility of developing a UK-specific design of MPC that could be flexibly used for all phases of SF management, including on-site dry storage, transport and disposal at a GDF. This work is currently in the conceptual design phase, but again thermal modelling is being used to understand the design constraints associated with the disposal of such large packages in a UK GDF.

A typical MPC design is illustrated in Figure 3 (note that separate overpacks would be used for storage, transport and disposal of such an MPC).

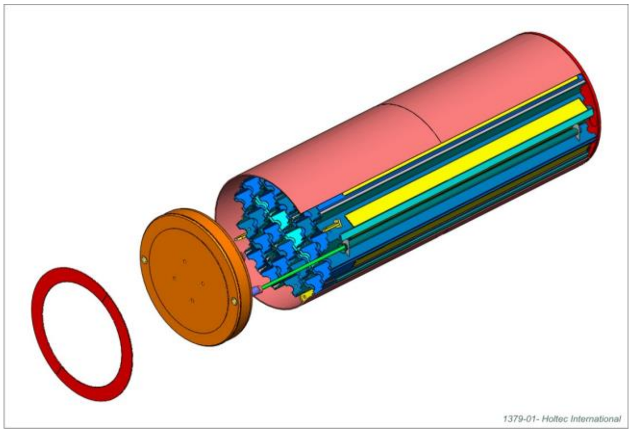

Figure 3 Generic Multi-Purpose Container for storage, transport and disposal of spent fuel

Current indications suggest that an MPC with a capacity for up to twelve PWR fuel assemblies could be compatible with UK transport and handling systems. The feasibility of disposing of such packages in a GDF is now being explored, including any requirements for deferred backfilling to comply with GDF thermal constraints. The study will determine the feasibility of maintaining underground openings for the requisite time periods, as well as ventilation and backfilling requirements. The MPC feasibility study will form part of the HHGW project outputs due during 2015.

VII. EXPLORING THE THERMAL IMPACT OF MIXED OXIDE SPENT FUEL DISPOSAL

As already highlighted, strategic decisions on how the UK stockpile of separated civil plutonium should be used have yet to be made. To support its strategy development, RWM completed an initial review of the disposability of irradiated MOX fuel that could be generated if such an option were implemented. This study was undertaken in support of NDA strategy development.

The thermal modelling completed for the MOX SF study identified that the disposal of unirradiated plutonium wasteforms would require careful management due to long-term heat output affecting the density with which the waste packages could be placed in a GDF.

Further work is currently being undertaken within the Disposability Assessment Process to further develop understanding of the thermal impact of different plutonium wasteforms in different concepts and host rock settings in support of NDA strategy development on plutonium disposition.

VIII. SUMMARY

The UK has a range of HHGW including legacy spent fuel, vitrified HLW and potentially new build and MOX spent fuels that may require geological disposal.

The UK nuclear regulators have implemented the ‘Generic Design Assessment’ process which enables them to begin assessing the environmental, safety and security aspects of new nuclear power stations designs prior to site-specific applications being made. RWM contributes to the GDA process by providing advice on the potential disposability of any new wastes and spent fuel generated as a consequence of operating new reactor designs through the Disposability Assessment Process.

The heat generated by legacy wastes and potential future wastes must be taken into account in the design of a UK Geological Disposal Facility. In the absence of a specific disposal site, RWM is developing generic disposal solutions for these wastes that take due account of the thermal load from such wastes, whilst taking account of the uncertainties that are currently associated with the siting of a UK GDF. To facilitate this, RWM operates the Disposability Assessment Process to provide advice to waste producing organisations on approaches to waste packaging and interim storage to ensure compatibility with future geological disposal requirements whilst taking due account of uncertainty.

REFERENCES

1. DEPARTMENT OF ENERGY AND CLIMATE CHANGE, “*Implementing Geological Disposal: A Framework for the Long-Term Management of Higher Activity Radioactive Waste”* (2014)
2. AMEC, “*Project Ankhiale: Disposability and full life cycle implications of high-heat generating wastes”*, AMEC report D.006297/001, Issue 1 (2012)
3. NDA, “*Geological Disposal – Generic Waste Package Specification”*, NDA/RWMD/067 (2012)
4. NDA, “*Geological Disposal – An overview of the generic Disposal System Safety Case”* (2010)
5. NDA, “*Feasibility studies exploring options for storage, transport and disposal of spent fuel from potential new nuclear power stations”*, NDA/RWMD/060 (2014)