Radioactive Waste Management

NDA/RWM/172

Geological Disposal

Generic Design Assessment: Summary of Disposability Assessment for Wastes and Spent Fuel arising from the Operation and Decommissioning of the UK HPR1000 Pressurised Water Reactor

June 2021

Conditions of Publication

ISBN 978-1-84029-608-2.

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Executive Summary

China General Nuclear Power Group (CGN) and Électricité de France (EDF), through their joint venture company General Nuclear System Limited (GNSL), has entered the Generic Design Assessment (GDA) process for the UK Hua-long Pressurised Reactor (UK HPR1000). At the request of GNSL, Radioactive Waste Management Limited (RWM) has undertaken a GDA disposability assessment to provide a preliminary judgement as to the potential acceptability for disposal to a geological disposal facility (GDF) of the waste packages expected to arise from the operation and decommissioning of the UK HPR1000. This disposability assessment will inform the GDA being undertaken by UK regulators.

This assessment has been based on information supplied by GNSL on the nature of operational and decommissioning higher activity solid radioactive wastes and spent fuel arising from the proposed UK HPR1000 and proposals for the packaging of these wastes. The GDA disposability assessment 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 proposals for the packaging of the HPR1000 wastes are based on the use of UK standard waste containers consistent with RWM standards and specifications. The issues identified from the GDA disposability assessment for the UK HPR1000 could all be resolved through appropriate development of the proposals. There are no issues that would challenge the disposability of the wastes and spent fuel expected to be generated from operation and decommissioning of the UK HPR1000. Given a disposal site with suitable characteristics, the wastes and spent fuel from the UK HPR1000 are expected to be disposable.

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1 Introduction

The 2008 White Paper on Nuclear Power [1], together with the preceding consultation [2], established the process of Generic Design Assessment (GDA) [3], whereby industry-preferred designs of new nuclear power stations would be assessed by regulators in a pre-licensing process. China General Nuclear Power Group (CGN) and Électricité de France (EDF), through their joint venture company General Nuclear System Limited (GNSL), is proposing to develop and construct in the UK a Hua-long Pressurised Reactor (UK HPR1000), and is therefore requesting assessment of the design under the GDA process.

The Government has set out its framework for managing higher-activity wastes (HAW) through geological disposal [4,5]. This process is based on the current inventory for geological disposal (IGD) [6] but it is intended to be capable of accommodating waste and spent fuel arising from any new build programme. Consequently, requesting parties will be expected to seek assurance from Radioactive Waste Management Limited (RWM) that the anticipated waste streams will be acceptable for disposal in such a facility [7].

The assessment of the disposability of the HAW and spent fuel from the UK HPR1000 is based on information on wastes and spent fuel, and proposals for waste packaging supplied by GNSL [8,9][1], supplemented as necessary by relevant information available to RWM.

The principal conclusions of this GDA disposability assessment are presented in this report, together with the details of the wastes and their characteristics, as applied in the assessment. More comprehensive details of the information supplied to RWM by GNSL, measures taken by RWM to supplement this information, assessment methods, and the detailed conclusions of the GDA disposability assessment, will be provided to GNSL in a separate Assessment Report.

The GDA disposability assessment 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) [10].

[1] *GNSL has updated these documents. RWM has used the referenced submission documents and information supplied, supplemented as necessary by information available to RWM and by further calculations, to provide a robust and comprehensive dataset of information covering waste package numbers, inventories, and general characteristics of the conditioned and packaged ILW and spent fuel.*

It is recognised that, at this early stage in the development of reactor designs and operating regimes, proposals are essentially outline in nature; and the detailed arguments and supporting evidence on the performance of the proposed packages are currently not available. This disposability assessment has made data enhancements using data from previous closely related assessments, and has made some assumptions, to allow the production of a comprehensive and detailed data set describing the ILW and spent fuel to be generated from operation and decommissioning of a UK HPR1000. At later disposability assessment stages, it is expected that more specific and detailed packaging proposals would be assessed, and potentially endorsed through the existing disposability assessment Letter of Compliance process (LoC) [11].

The GDA disposability assessment process is summarised in Appendix A and comprises three main components: a review to confirm the waste and spent fuel properties; an assessment of the compatibility of the proposed waste packages (defined as the waste container and wasteform) with concepts for the geological disposal of HAW; and identification of the main outstanding uncertainties, and associated research and development needs, relating to the future disposal of the wastes. A summary of the package characteristics, wasteform descriptions and packaging assumptions for ILW and spent fuel derived for the purposes of this GDA disposability assessment are set out in Appendix B.

2 Nature of the ILW and Spent Fuel

GNSL has provided information on the ILW and spent fuel expected to arise from a UK HPR1000 operating for 60 years. In line with the White Paper [1], spent fuel from a new build programme is assumed to be managed by direct disposal after a period of interim storage.

Three general categories of higher-activity waste and spent fuel are identified[2] for HPR1000:

- Operational wastes: ILW arising from the operation of a reactor;
- Decommissioning wastes: ILW arising from the eventual decommissioning of a reactor;
- Spent nuclear fuel arising from reactor operation.

Based on the stated assumptions, GNSL has provided information for the following seven types of operational ILW:

- Spent ion exchange resins (resins);
- Spent filter cartridges (cartridges);
- concentrates;
- Sludges;
- Non-fuel core components (NFCC), comprising of in-core instrumentation assemblies (ICIA), rod cluster control assemblies (RCCA) and stationary core component assemblies (SCCA).

GNSL has provided information for the following three types of decommissioning waste. Comprising of:

- Reactor pressure vessel (RPV);
- Reactor pressure vessel internals (RPVI);
- Decommissioning concrete (concrete).

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[2] In practice, operational and decommissioning wastes will comprise of ILW and low-level waste (LLW). LLW is assumed not to be destined for a GDF and is excluded from the disposability assessment.

Further development of reactor operation and decommissioning plans in the future will provide an improved understanding of the expected quantities of ILW, although that detail is not required for this GDA disposability assessment.

GNSL has provided information for the spent fuel. The Framatome AFA 3GTMAA fuel has been selected as the baseline fuel for the UK HPR1000, a type of fuel assembly that is widely used for Pressurised Water Reactors (PWRs) worldwide. The fuel assembly consists of ceramic UO_2 pellets encased in M5 alloy (a type of zirconium alloy). There are 177 fuel assemblies in the reactor core during operation. The assembly consists of up to 264 fuel rods supported by an orthogonal structure with a 17x17 square array. The skeleton of the assembly consists of a top nozzle and bottom nozzle, 24 guide thimbles, 1 instrumentation tube, 8 structural grids (6 of them being mixing grids), and 3 mid-span mixing grids. The instrumentation tube is located in the centre and provides a channel for insertion of an in-core neutron detector. The guide thimbles provide channels for insertion of different types of core components (namely RCCA and SCCA) whose type depends on the position of the particular fuel assembly in the core. The fuel rods are loaded into the skeleton to form the fuel assembly, in such a way that there is an axial clearance between the fuel rod ends and the top and bottom nozzles in order to accommodate the differential elongation of the skeleton and the fuel rods during operation. Information on spent fuel has been supplied by GNSL based on an assumed fuel assembly burnup of 47.4 GWd/tU (average) and 50.2 GWd/tU (maximum). It is proposed that the RCCA and SCCA core components would be disposed of inserted into the spent fuel assemblies (Spent Fuel and NFCC).

3 Proposals for Waste Packaging

GNSL has put forward practices for the packaging of operational ILW based on well-established current practice for similar ILW wastes in the UK. The disposability assessment has assumed that dried resins and ICIA wastes streams would be packaged (unencapsulated) in 500 L Robust Shielded Drums. The cartridges would be grout encapsulated in into 3 cubic metre boxes (3 m³ Boxes). The concentrates and sludges would be grout cemented in 500-litre drums (500 L Drums) using in-drum lost-paddle mixing, to ensure a homogeneous wasteform.

The proposals for the packaging of decommissioning ILW are based on the use of UK standard waste containers consistent with RWM standards and specifications. The RPV and concrete wastes are assumed to be grout cemented in 4 metre boxes (4 m Boxes) with 100-mm thick concrete walls and the RPVI is assumed to be grout cemented in 3 m³ Boxes.

The GDA disposability assessment for the spent fuel and NFCC from the UK HPR1000 was based on it being over-packed for disposal. For the purposes of this assessment, disposal using robust disposal containers manufactured from either copper or steel has been considered, this is consistent with the basis of the DSSC. It has been proposed that each disposal container would contain four fuel assemblies from a UK HPR1000.

The 500 L Drums and 3 m³ Boxes would be transported in standard waste transport containers (SWTCs), which would be manufactured in steel with three shielding thicknesses, 70mm (SWTC-70), 150mm (SWTC-150) and 285mm (SWTC-285). The 4 m Boxes will be transported as Industrial Package Type 2 (IP-2). The spent fuel and NFCC would be delivered to the disposal facility packaged in a disposal container, which in turn would be transported in a reusable disposal container transport container (DCTC).

Proposals for packaging ILW waste and spent fuel are described in more detail in Appendix B.

4 Radionuclide Inventory of ILW and Spent Fuel

The information supplied by GNSL on the estimated radionuclide inventories of the identified ILW and spent fuel have been used to derive package-specific inventories. These inventories are described in Appendix B. In all cases, except for the concrete waste stream, to ensure a full coverage of potentially significant radionuclides, it has been necessary to supplement the information supplied by GNSL using additional information available to RWM for similar waste types based on RWM generic assessment tools, and data from the assessment of wastes from similar reactor designs. The assessment inventories are intended to characterise the range of waste product package inventories, taking account of the potential variability between packages, and other uncertainties. Typically, an assessment inventory includes a best-estimate (average) and bounding (maximum) inventory for a waste package to encompass such variability and uncertainty. Two disposability assessments for UK PWRs have been completed previously: namely the EDF's European Pressurised Water Reactor (EPR) [12] and the Westinghouse Advanced Pressurized 1000 (AP1000) [13] reactors. These assessments provided useful inventory information for comparison and enhancement of equivalent HPR1000 operational and decommissioning waste streams.

When calculating inventories for HPR1000, the disposability assessment made the following assumptions for the timing of transport of packaged wastes to a GDF:

- Operational waste streams are transported to a GDF at 1 year after arising, except ICIAs, which are transported at 10 years after arising;
- Decommissioning waste streams are transported to a GDF at 15 years after the end of operation;
- Spent fuel assemblies are transported to a GDF at 10 years after the end of operation.

The proposed operating lifetime of the UK HPR1000 is 60 years. Discussion of the implications for management of radioactive waste assumes that the reactors latest operation period is 2070 to 2130. The assumed timings of reactor operation lead to short periods between waste arising and transport, but calculating radionuclide inventories and assessing their effects with these short time periods permits optimisation. For example, if external gamma dose rates are unacceptably high then the effects of extending the time periods ('decay period') can be explored to give additional time for radioactive decay and dose level reduction in the waste packages. GNSL did not propose any decay periods and it is recognised that significantly longer timescales between the time of waste arising and transport to a GDF than those stated above may be required.

For the spent fuel radionuclide inventory calculations, GNSL has proposed that the GDA disposability assessment for the UK HPR1000 should assume that the reactor would use fuel elements made from uranium dioxide, 4.45% enriched in U235, and operated to achieve a maximum fuel assembly burnup of 50.2 GWd/tU and an average burnup of 47.4 GWd/tU. Increased burnup implies that the fuel is used more efficiently and that the volume of fuel to be disposed of will be smaller per unit of electricity produced. However, increased irradiation leads to individual fuel assemblies with an increased concentration of fission products and higher actinides, leading in turn to assemblies with higher thermal output and dose rate.

In PWRs, the RCCA and SCCA are incorporated as part of the fuel assembly and GNSL propose that these NFCC waste streams are managed with the spent fuel. The radionuclide inventory for an average package assumes the average fuel burnup of 47.4 GWd/tU and an average arising inventory (lifetime average inventory for spent fuel and NFCC) at reactor closure plus 10 years cooling period. This takes account of regular fuel discharges over the lifetime of reactor operation. The maximum package case used conservative assumptions to ensure that the conclusions are robust. The radionuclide inventory for a maximum package assumed a maximum fuel burnup of 50.2 GWd/tU and that the spent fuel and NFCC arose at the end of reactor operation plus 10 years cooling period.

Uncertainties in the inventories arise from numerous sources, for example the detailed reactor operating regime adopted, including fuel burnup and waste package loadings and distribution. The GDA disposability assessment has used best endeavours to bound these uncertainties and thereby provide robust, conservative conclusions. It is anticipated that information on the inventories associated with the ILW and spent fuel would be refined as the design of the reactors and their operating regimes are developed further. Such information, together with more refined packaging proposals, would be considered at an appropriate time in the future through the LoC process. Uncertainties that will need to be addressed at later stages of assessment include:

- Uncertainties in gadolinium fuel inventories. Fuel assemblies differ in the enrichment of U235 and the number of uranium rods (UO_2) and Gd-doped uranium rods (UO_2-Gd_2O_3);
- More comprehensive inventory information and data is required (including, impurities in irradiated materials, hazardous substances and non-hazardous pollutants);
- Accounting for the variability of activation levels within the RPV and RPVI waste streams;
- Potential inclusion of steel reinforcement in decommissioning concrete.

RWM has concluded that the inventory data supplied by GNSL, augmented by supplementary data as required, has provided comprehensive and appropriate data sets, which are sufficient to provide confidence in the calculations of the GDA disposability assessment.

5 Assessment of Proposed ILW Packages

5.1 General Findings

The proposal to use RWM standard waste containers provides confidence that many aspects of the existing RWM standards and specifications for waste packaging will be complied with. The proposals for the packaging of operational and decommissioning wastes, except for resins and ICIAs, are based on solid wasteforms that provide for the immobilisation of the activity associated with waste. The proposed use of cementitious grout for waste conditioning conforms to existing practices for similar wastes in the UK and is expected to produce packages that would be compliant with existing RWM standards and specifications, and, therefore, with the use of an appropriate transport container, would be compliant with the systems assumed for transport of waste packages to, and disposal of waste packages in, a geological disposal facility. The proposals for not adopting a conditioning process for resins and ICIAs, can be a suitable approach for eliminating undesirable interactions between the waste and conditioning materials.

Within the UK, regulation of the transport of radioactive material is by compliance with regulations that, through international agreements, implement the International Atomic Energy Agency (IAEA) Transport Regulations. Limits are placed on the contents of a transport package in the IAEA Transport Regulations. RWM has a suite of Waste Package Specifications that also include limits on the contents of a transport package. The proposed transport packages have been assessed against the requirements of compliance with both sets of limits. The assessment has assumed that the transport of the waste packages (except for the 4 m Boxes which qualify as transport packages) would be based on transport in SWTCs to satisfy the requirements defined by the IAEA. The Transport Safety Assessment has only identified some minor waste specific issues.

The Operational Safety Assessment has not identified any fundamental safety issues with the proposed packages of ILW.

The Post-Closure Safety Assessment has screened the radionuclide inventory of the ILW waste streams against the basis of the DSSC. It has not identified any problematic radionuclides, or radionuclides present in the wastes at sufficiently high activities that there could be potential impacts on post-closure risks. The potential impacts of criticality events on post-closure safety have previously been subject to detailed investigation. For the HPR1000 ILW, the levels of the fissile radionuclides are very low, compared with the package averages considered in the DSSC. As such, the HPR1000 ILW waste streams will not change the overall conclusion that a criticality event in the GDF is unlikely to occur. A minor waste stream specific issue associated with the radiogenic heat output of the RPVI waste stream has been identified.

To show that wastes have been packaged efficiently (e.g. by the use of most appropriate container type and/or wasteform) it will be necessary at the future LoC assessment stage to undertake optioneering, if this has not already been completed (e.g. through Best Available Techniques or Best Practicable Environmental Option studies).

A disposal facility design impact assessment has been undertaken to evaluate the impacts from disposal of UK HPR1000 ILW operational and decommissioning wastes upon the published Generic Transport System and Disposal Facility Designs within the DSSC and associated IGD. The IGD defines the nature and quantity of historical wastes, currently arising wastes, and wastes from new nuclear build reactors. It is used by RWM to assist development of GDF design and safety cases. To retain consistency with the Implementing Geological Disposal White Paper, and the 16 GW(e) new build programme, the IGD incorporates wastes and spent fuel from six UK EPRs (each producing 1.6 GW(e)) and six AP1000s (each producing 1.14 GW(e)). However, it is acknowledged that the new build programme is still under development, with only four planned EPRs (two at Hinkley Point and two at Sizewell) and currently no AP1000 planned.

If the ILW waste packages arising from HPR1000 are assumed to be additional to the waste packages assumed to arise from new build by the IGD, then based upon the current design assumption, the additional ILW packages arising from a UK HPR1000 will only require a fractional length of a single additional vault for their disposal. It is noted that the types of waste and waste packages proposed from the UK HPR1000 are similar to those proposed for other PWRs and may be 'interchangeable' for wastes already assumed in the IGD without major revision. If the waste packages are assumed to be 'interchangeable' for waste packages that would arise from similar new build waste packages already assumed in the IGD, then no additional vault space would be required. The timing of arising of the HPR1000 may also be commensurate with other wastes arising from new build, and therefore may not impact upon the planned GDF programme or throughput rates. In either scenario above, the impact of ILW waste packages arising from a single HPR1000 upon the footprint of a GDF are negligible.

It is noted that for the operational ILW waste streams, the waste packages arisings from the UK HPR1000 reactor are significantly lower in number, less than half, than for the other new build reactors encompassed within the IGD. It could be the case that the proposals for other GDA disposability assessments for PWRs (already accounted for in the IGD) have been conservative in the estimation of operational ILW waste arisings, or that ILW arisings from the HPR1000 are underestimated, or that waste management practices are different. However, these differences can be addressed at the LoC stage.

5.2 Waste Specific Findings

GNSL proposes that the cartridge waste stream will be encapsulated in 3 m^3 Boxes. To meet RWM standards and specifications requires a detailed packaging solution to be developed, e.g. an effective process for immobilisation of radioactive materials and ensuring voidage minimisation (i.e. effective infiltration of grout into the cartridges). For the concentrate and sludges waste streams encapsulated in 500 L Drums, it will be necessary to develop appropriate encapsulant formulations and demonstrate that the waste has been rendered into an effectively passive and monolithic form, while also accounting for species, such as boron and zinc, that may interfere with the cementation process.

The proposals to package resin and ICIA wastes in 500 L Robust Shielded Drum without encapsulation relies on the performance of the waste container to provide the physical and/or chemical containment of the radionuclides and other hazardous materials associated with the waste. Part of the philosophy for the use of robust shielded waste containers for the packaging of ILW is that it reduces the need for the wasteform to make a significant contribution to waste package performance. The performance of the specific design of robust drum will need to be demonstrated in subsequent LoC submissions.

For the ICIA wastes, GNSL has proposed a new design of the 500 L Robust Shielded Drum which includes an additional 150mm of steel shielding, this drum design will require development requirements for the specific designs and materials used, and the performance of this new design will need to be demonstrated in subsequent LoC submissions for the UK HPR1000 wastes. For ICIA waste packages, the radiogenic heat output of maximum package, with conservatively assumed decay period of 10 years, may exceed the target value of 3W at the time of disposal vault backfilling (dependent on when HPR1000 reactor(s) operates relative to GDF plans), and therefore, a slightly longer decay period may be required.

For the unencapsulated wastes, GNSL will need to develop appropriate waste treatments as necessary, such as removing free liquids (e.g. a suitable resin de-watering process). It may also be necessary to develop additional processes for minimising voidage (e.g. through use of a void filler), however this need may be dependent on DSSC developments and GDF siting. Demonstration of the package performance should be achievable, as similar proposals have been assessed at the LoC stage for resins arising from Sizewell B and Magnox power stations, and the wastes assessed as disposable.

For decommissioning wastes, GNSL proposes to package RPV and concrete wastes in 4 m Boxes with 100 mm concrete shielding. The RPV waste package dose rates do not meet transport limits with the assumed decay period of 15 years, if limits for non-exclusive use are applied. The less onerous dose rate limits could be applied for compliant transport under exclusive use. Nevertheless, transport with such high dose rates could have implications for compliance with reducing doses to as low as reasonably practicable (ALARP) and could also have design or operational implications for a GDF. For dose reduction GNSL should consider additional shielding, and/or a longer decay period (estimated at 40 years after reactor shutdown for the maximum package) prior to package transport. GNSL will also need to consider the heterogeneity of the RPV wasteform and the impact on external dose rates. For the concrete and RPV waste packages, the dose rates for the average and maximum package are significantly below the limits for transport, therefore, the level of shielding can be optimised to take account of the low level of dose challenge (by the application of efficient resource use). Additionally, the no loss or dispersal requirement for an IP-2 transport package could be breached if the package is vented during transport. However, a package left unvented for an extended period of time may present issues around flammable gas build up in the ullage. The 'no loss or dispersal' is not unique to the HPR1000 and RWM has a programme of work planned to look at this issue. Alternatively, if necessary, GNSL could consider other packaging, container and/or transport options.

GNSL proposes to grout encapsulate RPVI in 3 m³ Boxes. As currently proposed, the waste loadings are near the mass limit for the package type and this packing efficiency may not be achievable; therefore, GNSL should consider dividing the waste between more waste packages. Additionally, the high internal dose rates within the RVPI waste packages and the radiogenic heating from radioactive decay may have implications for the long-term integrity of the grouted wasteform due to the cracking and spalling of cement grouts that can occur under gamma irradiation as a result of radiolytic hydrogen build-up in the pores; and radiogenic heating may also contribute to drying and cracking of a cement grout. To mitigate this, appropriate cooling periods and a wasteform formulation development programme will be required. The RPVI waste packages transported in SWTC-285 do not meet the transport limits for dose rate and radiogenic heat output with the conservatively assumed decay period of 15 years. The RPVI packages transported also fail to comply with the limit for containment under Accident Conditions of Transport due to the estimated release rates of tritium into the SWTC cavity during a fire accident scenario. An extended period (several decades) prior to transport, to allow further radioactive decay, and refinement of package performance; should allow RPVI packages to meet dose rate, package heat output limits and containment under Accident Conditions of Transport. The radiogenic heat output at the GDF closure date could also be high, depending on the timing of HPR1000 shut down and GDF closure, but this could be managed with an appropriate period of decay. Further consideration of these issues will be required during the LoC assessment stages. Similar issues were not identified for GDA assessment of wastes from other PWRs, but in these cases significantly extended periods of storage for radioactive decay post-shutdown, prior to transport, were proposed by the requesting parties.

5.3 Conclusions for ILW Packages

Overall, the proposals for the packaging of operational and decommissioning ILW have been judged to be potentially viable, and consistent with plans for geological disposal. While further development needs have been identified, including the need to demonstrate the expected performance of the proposed waste packages, and a potential need for an extended decay period (of the order of several decades) for decommissioning wastes beyond that conservatively assumed by RWM, these would be the subject of future assessment under the LoC process when further details on the packaging proposals have been developed.

6 Assessment of Spent Fuel/ RCCA/SCCA Packages

6.1 Findings

Assessment of packaging proposals was based on sealing dry spent fuel assemblies, along with their associated NFCCs (specifically one RCCA or SCCA), inside durable disposal containers manufactured from suitable materials, which would provide long-term containment for the radionuclide inventory. The disposal container material is expected to depend on the GDF geology, and this remains to be confirmed. At this time the disposability assessment process considers the performance of two types of containers, copper containers and carbon steel containers. In the copper container case, it is assumed that a cast-iron insert is used to hold and locate the spent fuel assemblies, and to provide mechanical strength. In the carbon steel container case, a carbon steel “tube and plate” basket is used to hold and locate the spent fuel assemblies. RWM recognises that the performance of disposal containers will be an important element of a safety case for the disposal of spent fuel. Consequently, it is anticipated that RWM will continue to develop container designs, with the intention of substantiating current assumptions and tailoring the designs to whatever site is ultimately identified.

The Transport Safety Assessment has only identified some minor issues, all of which are considered resolvable. The estimated dose exceeds the limit for transport for the maximum waste package inventory at the assessment inventory date under exclusive use, but a further decay period of a decade would bring the waste packages within this transport limit. The maximum inventory waste package also has a heat output such that thermal shielding would need to be incorporated into the design of the DCTC, although, a further period of decay beyond the assessment inventory date will reduce that challenge. A final design for the DCTC, including contents limits, will not be available for several years. Nevertheless it is judged that sufficient flexibility exists in the outline designs for transport of spent fuel disposal packages to a GDF, to allow suitable arrangements to be developed for the transport of containers with HPR1000 spent fuel and NFCCs.

The Operational Safety Assessment has not identified any significant issues. It was noted that gamma irradiation of beryllium in the SCCA may increase the neutron dose rate above that expected from spent fuel alone, and this will need to be considered further in future assessments.

As part of the Post-Closure Safety Assessment the radionuclide inventory of the spent fuel and NFCCs was screened against the radionuclide inventory used for the DSSC. No issues were identified in terms of problematic radionuclides, and no radionuclides are present in the wastes at sufficiently high activities that there could be potential impacts on post-closure safety risks. The potential impacts of criticality events on post-closure safety have previously been considered. For the spent fuel, the initial enrichment and the maximum fuel burnup are close to the values for the PWR spent fuel from the Sizewell B reactor, for which a post-closure criticality is considered not credible. As such, the HPR1000 waste streams will not change the overall conclusion that a criticality event in the GDF is unlikely to occur. For criticality compliance, RWM is likely to need to take credit for fuel burnup so that compliance with post-closure criticality safety case can be demonstrated. This emphasises the need for GNSL to keep accurate records of fuel irradiation. The intentional inclusion of neutron sources has not been considered previously by RWM and although it is not considered to be a criticality risk it does need to be considered, with beryllium content, as part of a future criticality safety case.

The spent fuel and NFCC packages present some challenges, for example, if the spent fuel and NFCC are wet stored prior to packaging, there could be a potential issue for water carry-over (e.g. within the thimbles plugs), and therefore steps to control water carryover to an acceptable level would need to be implemented before packaging to reduce the potential for container corrosion and pressurisation.

Planning for the transport and disposal of packaged spent fuel to a GDF is at an early stage of development. Consequently, the UK HPR1000 GDA assessment may influence necessary developments, for example, GNSL proposals to co-dispose of NFCCs inserted in the spent fuel assemblies. The length of the container required for the co-disposal of spent fuel and NFCC has not yet been defined, but it is estimated to be within the 5.2 m length container required for fuel from the EPR. The DCTC requires development to accommodate disposal containers for new build fuels such as EPR fuel assemblies and HPR1000 fuel combined with NFCCs. Increasing the length of the DCTC will increase the gross mass of the loaded DCTC, estimated by this assessment to be approximately 60 tonnes. RWM has concluded that this estimated gross mass should be feasible to transport.

The potential impact of the disposal of UK HPR1000 spent fuel on the size of the geological disposal facility has been assessed. The 16GW(e) of new build assumed in the DSSC has been estimated by RWM to produce 8942 spent fuel containers that will fill, depending on the geology, approximately 310-336 disposal tunnels in a GDF. The assumed operating scenario for a single UK HPR1000 gives rise to an estimated 747 spent fuel and NFCC disposal containers, giving a small increase in disposal footprint for a GDF in all three geologies, however, if the spent fuel arising from HPR1000 is interchangeable for wastes already assumed in the IGD, then there will be no increase in footprint. The required number of disposal tunnels is consistent with the estimates for other new build reactors.

Based on the operation of other PWRs, it is possible that fuel assemblies may contain Gd-doped uranium rods (UO_2-Gd_2O_3). Currently there is no indication on the quantity of gadolinium, and the submitted radionuclide inventory implies that it is absent. However, it is noted that Gd-doped uranium rods have been assessed for previous GDAs [12,13,14] and no issues were found. Further assessment will be required in the future to account for Gd-doped fuel should they be proposed.

6.2 Disposal Vault Thermal Modelling

The materials used as part of the engineered barrier system, and the characteristics of the host rock, will affect the thermal criteria used to determine the acceptability of the heat output from waste packages consigned for disposal (see Appendix B4.3).

In higher strength rock (HSR), the temperature criterion requires that the temperature of the inner surface of the bentonite buffer should not exceed 100°C. In lower strength sedimentary rock (LSSR), the temperature criterion is that the buffer temperature should not exceed 125°C at its mid-point. In evaporites, the temperature criterion is that the temperature of the host rock should not exceed 200°C. Adopting the spacing used in the illustrative designs for HSR (bounding geology for the thermal criteria used to determine the acceptability of waste packages), the average package inventory was found to be suitable for emplacement after 5 years of additional cooling beyond the inventory date basis described above. Whereas, the maximum package inventory would need 54 years of additional cooling before emplacement. For the maximum package, additional cooling times are reduced for the LSSR with the maximum package inventory being emplaced with 34 years of cooling for this scenario. The evaporite geology is the least onerous case and the maximum inventory package could be emplaced with only 5 years additional cooling under this scenario. Cooling times for the maximum package emplacement in HSR can be further reduced to 38 years by 'checker boarding' the waste packages, this is essentially a 50% split between maximum and average packages within each disposal tunnel. Cooling times before emplacement could be further reduced by the following methods, however these will have implications (e.g. cost of additional containers, Disposal Tunnels and GDF footprint):

- Packaging three spent fuel assemblies into a Disposal Container, rather than four;
- Increasing spacing of containers, either by spacing Disposal Tunnels further apart or spacing the Disposal Container Deposition Holes further apart.

These cooling times are dependent on a number of uncertainties, in particular the conservative assumptions made in developing the maximum package inventory for spent fuel and NFCC (not taking any credit for the cooling that would have occurred for much of the fuel used early in operation of the power plant, instead assuming that it is all at the maximum activity at reactor closure plus 10 years), the uncertainty in the thermal conductivity of the host rock, and the details of the underground design (e.g. package spacing). This uncertainty could be reduced by further work, for example, through refinement of the assessment inventory and by taking into account the cooling of the spent fuel being stored prior to the end of the operational period (i.e. 'mix-and-match' longer decayed fuel with shorter decayed fuel to provide lower maximum dose rates and heat outputs from the packages), though there is no requirement to undertake this for GDA disposability assessment. These conclusions are similar to those reached for PWRs assessed for previous GDA assessments [12,13].

7 Summary of Findings

The GDA disposability assessment has identified a number of issues that RWM anticipates could be resolved by future refinements of the radionuclide inventories of the higher-activity wastes, complemented by the development of more detailed proposals for the packaging of the wastes and spent fuel, and better understanding of the expected performance of the waste packages. It is expected that more specific and detailed packaging proposals would be assessed through the established disposability assessment process.

The key issues that will require further consideration in support of a future disposability assessment include:

- For unencapsulated wastes, the resins and ICIAs, GNSL will need to develop specific packaging solutions, such as removing free liquids (e.g. a suitable resin de-watering process) and, if necessary, minimising voidage (e.g. void filler).
- Reactor Pressure Vessel waste packaged in 4 m Boxes with 100 mm concrete shielding do not meet transport dose rate limits based on a radionuclide inventory derived using a short decay period of 15 years post-shutdown as applied by RWM to test the proposals. For dose reduction GNSL should consider additional shielding, and/or a longer decay period (estimated at 40 years after reactor shutdown for the maximum package) prior to package transport.
- Reactor Pressure Vessel Internals waste packaged in a 3 m³ Boxes and transported in SWTCs with 285 mm of shielding, do not meet the transport limits for dose rate; heat output and containment under Accident Conditions, with the short decay period of 15 years post-shutdown as applied by RWM to test the proposals. An extended decay period of several decades prior to transport, to allow further radioactive decay, and refinement of package performance, would allow RPVI packages to meet dose rate, package heat output limits and containment under Accident Conditions of Transport.
- 4 m Boxes for packaging RPV waste and concrete may breach the 'no loss or dispersal' requirement for an IP-2 transport package if vented during transport. A package left unvented for an extended period of time may present issues around flammable gas build up in the ullage. This is not unique to the HPR1000 proposals and a programme of work is being undertaken by RWM to look at this issue. It may be possible for RWM to justify venting of the 4 m Boxes packages, but GNSL could also consider other packaging, container and/or transport options should that become necessary.
- For the post-closure phase, the RPVI waste packages challenged the heat output criteria at the time of disposal vault backfilling, however this issue could be managed with an appropriate period of decay.

- For ICIA waste packages, the radiogenic heat output of maximum package, with conservatively assumed decay period of 10 years, may exceed the target value of 3W at the time of disposal vault backfilling (dependent on when HPR1000 reactor(s) operates relative to GDF plans), and therefore, a slightly longer decay period may be required.
- For the spent fuel and NFCC packages, the radiogenic heat output from waste packages consigned for disposal may not meet the thermal criteria used to determine the acceptability unless managed through a sufficient decay period, or control of packaging and/or emplacement.
- For spent fuel and NFCC packages criticality compliance, RWM is likely to need to take credit for fuel burnup so that compliance with post-closure criticality safety case can be demonstrated. This emphasises the need for GNSL to keep accurate records of fuel irradiation. The intentional inclusion of neutron sources has not been considered previously by RWM and although it is not considered to be a criticality risk it does need to be considered, with beryllium content, as part of future criticality safety case.
- At future disposability assessment stages, fuel management options (i.e. 'mix-and-match' longer decayed fuel with shorter decayed fuel to provide lower maximum dose rates and heat outputs from the packages; and refinement of the inventory) will need to be investigated to allow disposal of HPR1000 fuel at a GDF within the current assumed closure of a geological disposal facility commencing in 2190, whilst complying with buffer temperature limits.

8 Conclusions

RWM has undertaken a GDA disposability assessment for the higher-activity wastes expected to arise from the operation of a UK HPR1000. This assessment has been based on information on the nature of operational and decommissioning ILW and spent fuel, and proposals for the packaging of these wastes, supplied to RWM by GNSL. This information has been used to assess the implications of the disposal of the proposed waste packages against the waste package standards and specifications developed by RWM, and the supporting safety assessments for a proposed geological disposal facility. The safety of transport operations, handling and emplacement at a geological disposal facility in the UK, and the longer-term performance of the system have been considered, together with the implications for the size and design of a geological disposal facility.

RWM has concluded that sufficient information has been provided by GNSL to produce valid and justifiable conclusions under the GDA disposability assessment. The proposals for the packaging of the HPR1000 wastes are based on the use of UK standard waste containers consistent with RWM standards and specifications. The issues identified from the GDA disposability assessment for the UK HPR1000 could all be resolved through appropriate development of the proposals. There are no issues that would challenge the disposability of the wastes and spent fuel expected to be generated from operation and decommissioning of the UK HPR1000. Given a disposal site with suitable characteristics, the wastes and spent fuel from the UK HPR1000 are expected to be disposable.

It is expected that these conclusions would be supported and substantiated by future refinements of the radionuclide inventories of the HAW and spent fuel, complemented by the development of more detailed proposals for the packaging of the wastes and spent fuel, and better understanding of the expected performance of the waste packages. More specific and detailed packaging proposals should be assessed in the future, and potentially endorsed, through the established LoC process for assessment of waste packaging proposals.

Appendix A - Approach to GDA Disposability Assessment

UK IGD is the basis for the disposability assessments in the DSSC. Higher activity wastes are broadly sub-divided between Low Heat Generating Waste (LHGW), and High Heat Generating Waste (HHGW), alongside high fissile waste. LHGW is ILW arising from operating and decommissioning of reactors and other nuclear facilities, together with a small amount of Low-Level Waste (LLW) unsuitable for near surface disposal, in addition to stocks of depleted, natural and low-enriched uranium. HHGW comprises spent fuel from existing and future power stations and High-Level Waste (HLW) from spent fuel reprocessing. The HHGW inventory also includes high fissile activity waste plutonium, and highly enriched uranium. The HAW associated with a 16GW(e) new build programme are included in the IGD, and this sets the baseline against which the UK HPR1000 can be assessed.

The GDA disposability assessment process is an important stage in the assessment of a proposal from a Requesting Party, giving an early indication of the magnitude of the impact of the proposal on the GDF and providing some confidence that the proposed waste arisings will be compatible with current UK regulations and the developing DSSC [10]. Disposability assessment for GDA is not designed to result in endorsement by issue of a LoC.

The main purposes of a disposability assessment for GDA are to:

- Provide an indication of the likely magnitude of the impact of the proposal on the generic GDF design, footprint and operations for the accommodation of the potential waste arisings;
- Give confidence to a Requesting Party that the implementation of their proposals for waste packaging will result in waste packages that will be compliant with transport to, and disposal in a GDF, as currently foreseen;
- Provide RWM with confidence that the disposal concepts considered within the DSSC will be appropriate for the potential waste arisings;
- Propose solutions to potential problems.

The GDA disposability assessment comprises of three phases (Technical Evaluations, Design Impact Evaluations, and Safety and Environment Assessments) shown in Table A1.

Table A1 Three phases of the GDA disposability assessments and the corresponding evaluation and assessment areas

Phase 1: Technical Evaluations	
Waste Package Data	Definition of waste types for assessment. Provision of inventory data for assessment (Assessment Inventory), including necessary enhancements. Assessment of waste volume and uncertainties.
Nature and Quantity of Waste	Assessment of data quality. Confirmation and reporting of basis for Assessment Inventory.
Wasteform Properties	Review of proposed waste conditioning and identification of alternative processes. Definition of package numbers. Consideration of development needs. Assessment of spent fuel characteristics.
Phase 2: Design Impact Evaluations	
Design Impact	Impact of the proposed packaged on facility footprint and design requirements. Consistency with current specifications. Effect of heat and necessary cooling.
Waste Package Properties	Covering Fire and Impact Performance. Confirm that the proposed waste packages are consistent with RWM Waste Package Specifications, or otherwise highlight potential inconsistencies. Confirm that the proposed waste packages (and any proposed transport system) are consistent with the Generic Disposal System Designs developed from the Generic Disposal System Specification, or otherwise highlight potential inconsistencies.
Security	Comparison of wastes against existing criteria. Confirmation of Safeguards status.
Phase 3: Safety and Environmental Assessments	
Transport Safety	Compliance with deterministic transport requirements. Analysis of expected transport risks to confirm compatibility with concept. Significance of spent fuel compared to current understanding.
Operation Safety	Analysis of expected operational risks to confirm compatibility with concept.
Post-Closure Safety	Analysis of expected post-closure risks to confirm compatibility with concept.
Environmental Issues	Analysis of proposals with regard to protection of human health and the natural environment.

Appendix B - UK HPR1000 Operation and Decommissioning Wastes - Packaging Proposals and Package Characteristics

This Appendix provides a summary of the information used in the GDA disposability assessment for the UK HPR1000, this is based on information supplied by GNSL, and calculations by RWM to define waste package characteristics.

This section contains the following information:

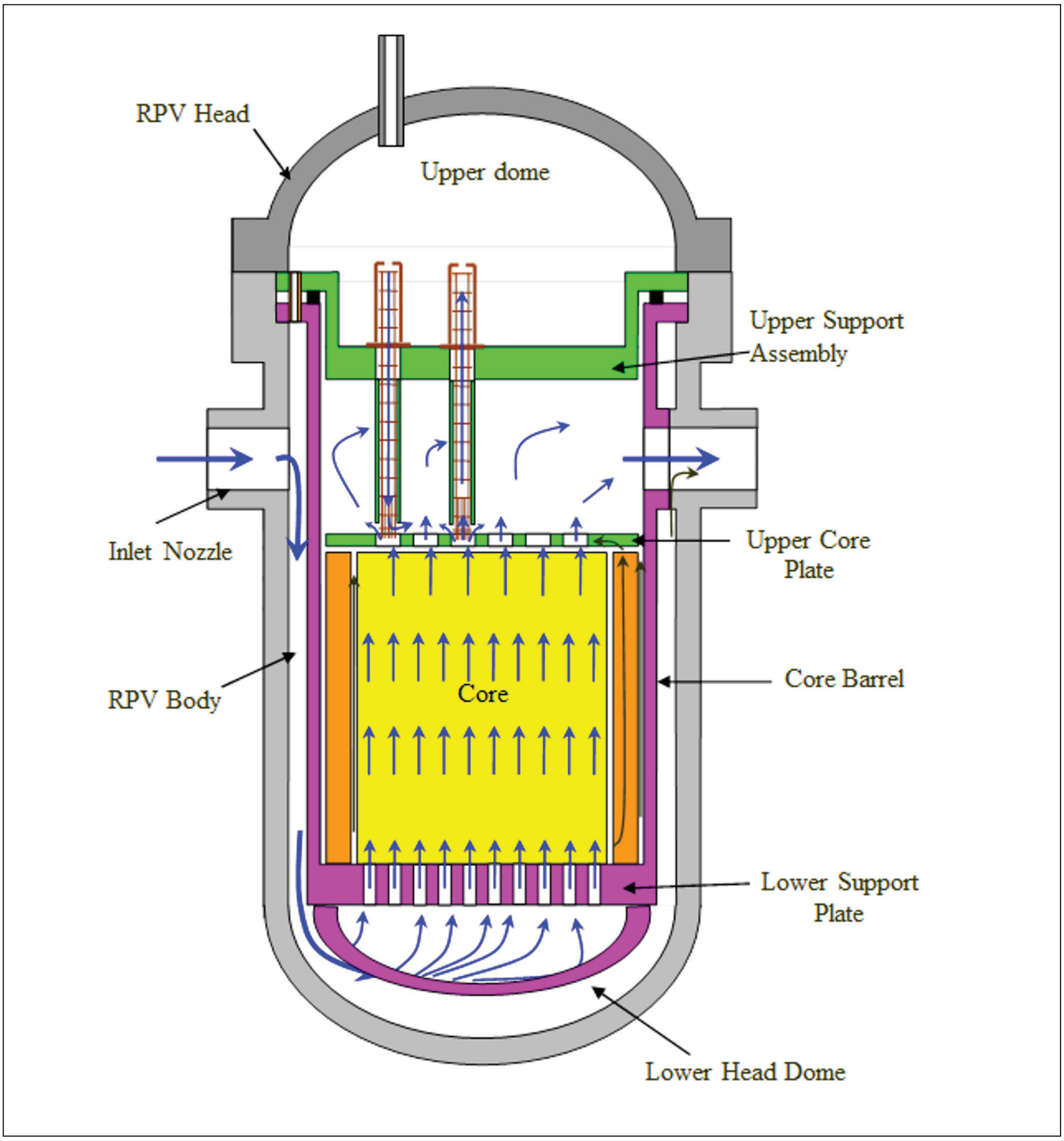
- Summary description of a UK HPR1000;
- Assumptions regarding the operation of a UK HPR1000;
- Description of the ILW radioactive waste streams and spent fuel that will be generated through the operation and decommissioning of a UK HPR1000 (the 'assessment inventory'), including volumes, assumptions regarding the packaging of these wastes and estimates of waste package numbers and their characteristics.

B1 Summary of UK HPR1000 Design and Operation

The UK HPR1000 is a PWR that has been developed by CGN, a company with over 30 years' experience of designing, constructing and operating nuclear power stations in China [15]. The reference plant of UK HPR1000 is the Hua-long Pressurised Reactor (HPR1000 - FCG3), which is currently under construction at Fangchenggang, Guangxi, China. The design and operation of UK HPR1000 and its reference plant, are based on CGN operating fleet of PWRs (namely, the CPR1000). Once built, a UK HPR1000 nuclear power station will comprise a 1180MW reactor unit.

In PWRs such as the HPR1000, ordinary (light) water is utilised to remove the heat produced inside the reactor core by thermal nuclear fission. This water also 'thermalises' or moderates' neutrons in a manner necessary to sustain the nuclear fission reaction. The heat produced inside the reactor core is transferred to the turbine through the steam generators. Only heat is exchanged between the reactor cooling circuit (primary circuit) and the steam circuit used to feed the turbine (secondary circuit), no exchange of cooling water takes place. The reactor core, which provides the heat source for steam generation, is housed in a RPV (Figure B1).

Figure B1 Schematic of UK HPR1000 RPV and internals, reproduced from [16]



B2 Assumptions

The GDA disposability assessment for the UK HPR1000 was based on the following assumptions:

- The UK HPR1000 would be operated for 60 years;
- The date at which operation of power production from a UK HPR1000 would commence in the UK is uncertain. In the GDA disposability assessment for the UK HPR1000, estimates of time-dependent properties, e.g. those related to radioactive decay, are assessed from time of generation of the waste;
- The fuel used in the UK HPR1000 will be manufactured from freshly mined uranium (i.e. not reprocessed uranium);
- It is assumed that ILW and spent fuel from the UK HPR1000 will arrive at a geological disposal facility in a packaged state, ready for disposal.

B3 Operational and Decommissioning ILW Streams - Packaging Assumptions, Package Numbers and Characteristics

B3.1 Operational and Decommissioning LHGW Streams

GNSL has proposed that seven operational ILW streams would arise from normal operation of a UK HPR1000:

- Ion-exchange resins (resins) which are used for removal of dissolved radioactivity from liquid wastes;
- Spent filter cartridges (cartridges) arising from the liquid waste treatment system;
- Concentrates derived from the evaporator in the liquid waste treatment system;
- Sludges arising from the sumps and tanks associated with the water auxiliary circuits;
- Non-fuel core components (NFCCs), comprising of, in-core Instrumentation assemblies (ICIAs), rod cluster control assemblies (RCCAs) and stationary core component assemblies (SCCAs).

GNSL proposes to package RCCAs and SCCAs with spent fuel, these NFCC waste streams are covered under spent fuel in Section B4.

GNSL has indicated that three decommissioning ILW streams would arise from normal operation of a UK HPR1000:

- The reactor pressure vessel (RPV);
- Reactor pressure vessel internals (RPVI);
- Decommissioning concrete (concrete).

Other decommissioning plant items may arise (e.g. piping, cooling ponds contaminated with sludge; decommissioning particulates and debris). The full decontamination and decommissioning processes have not yet been defined, and in the absence of further information are not quantified at this Stage.

The raw waste volumes, assumed packaging, transport container and package numbers of each HAW stream expected to arise through operation and decommissioning of a UK HPR1000 are provided in Table B1.

Table B1 Raw waste quantities, assumed packaging and package numbers for operational and decommissioning waste from a UK HPR1000 [1]

Waste Stream and *Identifier* [2]	Raw Waste Quantity	Assumed Waste & Transport Package [3]	Waste per Package	No. of Waste Packages
Operational Waste Streams				
Spent Ion Exchange Resins	112 m^3	500 L Robust Shielded Drum/ SWTC-150	0.466 m^3	240
Spent Filter Cartridges	79.2 m^3	Grouted into 3 m^3 Boxes /SWTC-285	0.660 m^3	120
Concentrates	43.8 m^3	Grouted ILW into 500 L Drums/ SWTC-70	0.230 m^3	190
Sludges	3.01 m^3	Grouted ILW into 500 L Drums/ SWTC-285	0.230 m^3	13
In-core Instrumentation Assemblies (ICIA)	8.12 m^3	500 L Robust Shielded Drums with 150 mm Additional Steel Shielding/ SWTC-150	8 sets	75
Rod Cluster Control Assemblies (RCCA)	1.96 m^3	Packaged with spent fuel	NFCC packaged with spent fuel (1 RCCA or 1 SCCA)	n/a
Stationary Core Component Assemblies (SCCA)	0.500 m^3			n/a
Decommissioning Waste Streams				
Concrete	152 m^3	Grouted into 4 m Boxes with 100 mm Concrete Shielding / IP-2	9.50 m^3	16
Reactor Pressure Vessel (RPV)	50.3 m^3		2.96 m^3	17
RPV Internals (RPVI)	18.0 m^3	Grouted into 3 m^3 Boxes/ SWTC-285	0.900 m^3	20
Spent Fuel				
Spent Fuel and Non-Fuel Core Components (Spent Fuel and NFCC)	2985 assemblies	Spent Fuel Disposal Container/ DCTC	4 assemblies with 1 RCCA or 1 SCCA	747

[1] *RWM supplements, as necessary, information supplied by GNSL to provide robust and comprehensive datasets of information covering waste package numbers, inventories, and general characteristics of the conditioned and packaged ILW and spent fuel. This has led to minor differences between the values submitted by GNSL and those used by RWM.*

[2] *Waste stream identifier highlighted by bold italics;*

[3] *Standard Waste Transport Container manufactured in steel with three shielding thicknesses, 70 mm (SWTC-70), 150 mm (SWTC-150) and 285 mm (SWTC-285); Industrial Package Type 2 (IP-2) and Disposal Container Transport Container (DCTC).*

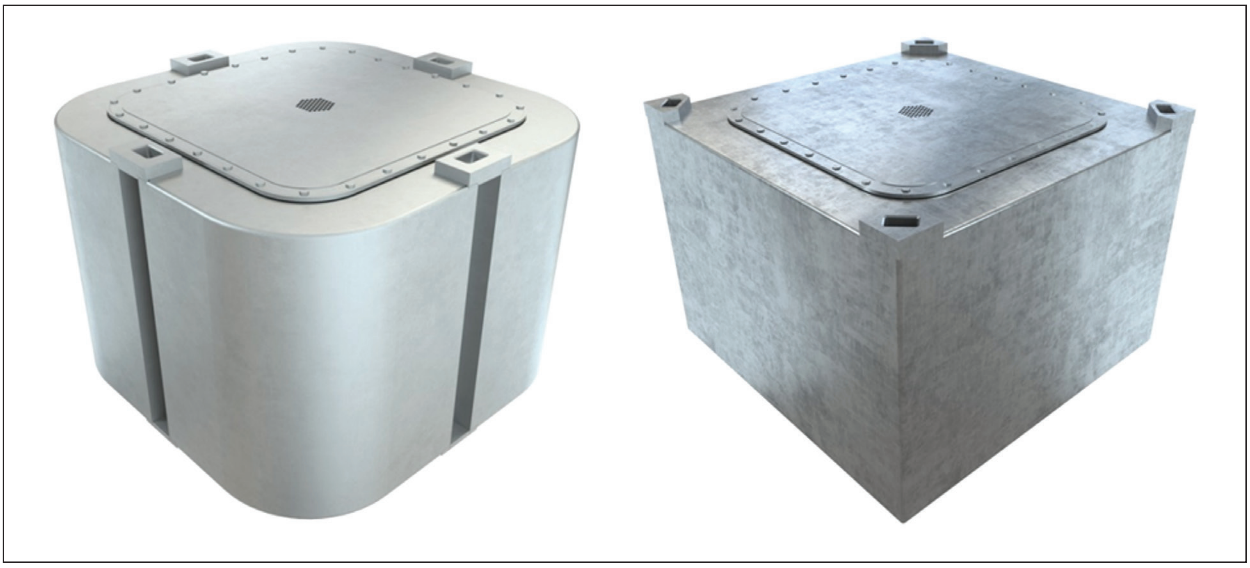
B3.2 Operational ILW Streams and Packaging Assumptions

To package the concentrates and sludges, it is proposed that the wastes would be grout cemented into 500 L Drums. The 500 L Drum waste container is illustrated in Figure B2.

Figure B2 Illustration of a 500-litre drum as proposed for packaging of some operational ILW from a UK HPR1000.

For transport, the 500 L Drums would be carried inside a Standard Waste Transport Container (SWTC), which is being developed by RWM to transport such waste packages. The SWTC is proposed to be manufactured in steel with three shielding thicknesses, 70 mm, 150 mm and 285 mm. Based on RWM assessment the 500 L Drums containing the concentrates would be transported in an SWTC-70. Under the stated inventory assumptions, the 500 L Drums containing sludges would be transported in an SWTC-285 and could be transported in SWTC-70 if decayed for longer period. To package the resins and ICIA, it is proposed that the wastes would be packaged into 500 L Robust Shielded Drums. The 500 L Robust Shielded Drum packages would be transported in an SWTC-150. Both the 500 L Drum and 500 L Robust Shielded Drum are standard RWM waste containers. To package the filter cartridges, it is proposed that the wastes would be grout cemented into 3 m³ Boxes. Under the stated inventory assumptions, the cartridge waste packages would need to be transported in an SWTC-285. The 3 m³ Box is a standard RWM waste container and is illustrated in Figure B3.

Figure B3 Illustrative examples of 3 m³ Boxes, one version of which could be used for packaging of operational and decommissioning ILW from a UK HPR1000.

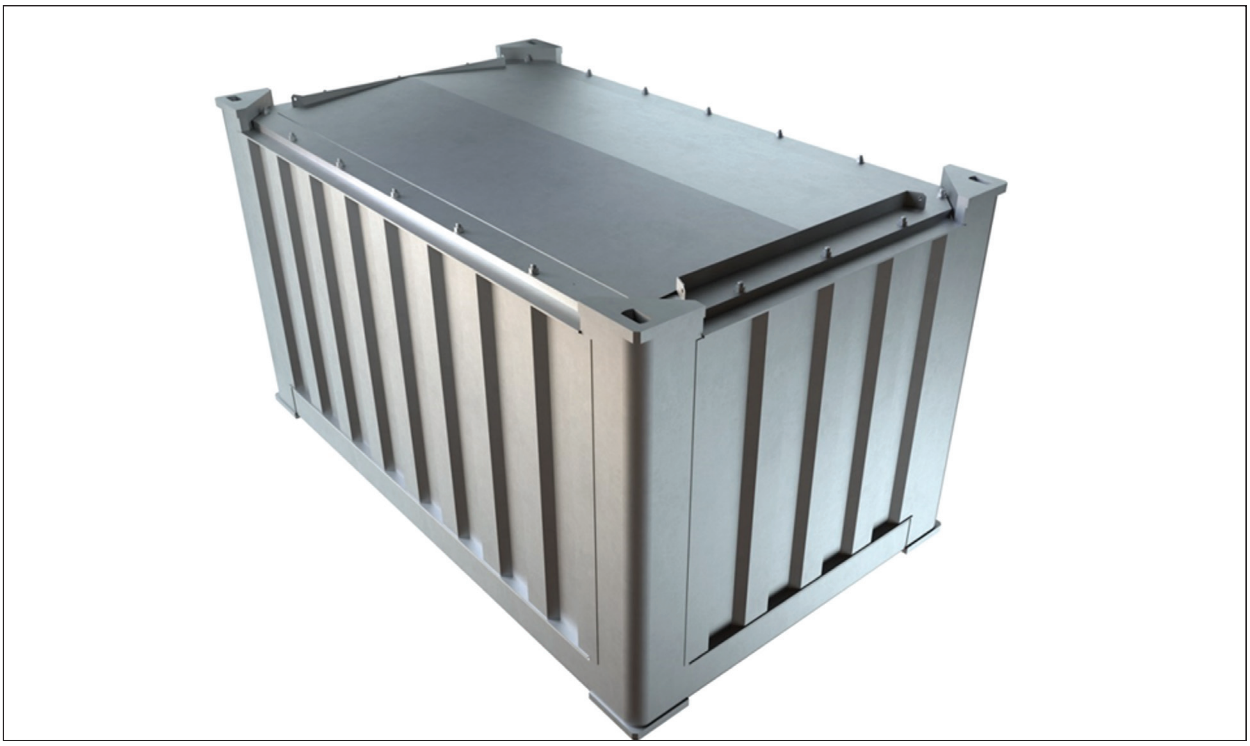


B3.3 Decommissioning ILW Streams and Packaging Assumptions

To package the RPVI waste, it is proposed that the wastes would be grout cemented into 3 m³ Boxes. It is assumed that the RPVI waste packages would be transported in an SWTC-285.

To package the RPV and concrete, it is assumed that the wastes would be grout cemented into 4 metre boxes (4 m Boxes) with 100 mm additional concrete shielding. The 4 m Boxes would be transported as IP-2 packages. The 4 m Box is illustrated in Figure B4.

Figure B4 Illustration of a 4 m Box as proposed for packaging of decommissioning ILW from a UK HPR1000.



B3.4 ILW Waste Stream Characteristics

The information supplied by GNSL on the radionuclide inventories of the identified wastes has been used to derive assessment inventories for the various proposed waste packages. To ensure a full coverage of potentially significant radionuclides it has been necessary to supplement the information supplied by GNSL with information available to RWM. The assessment inventories are intended to characterise the range of waste package inventories, taking account of uncertainties and variability between packages.

In support of this GDA disposability assessment, the assessment inventory included:

- A best-estimate (average) waste package inventory for each package type. This inventory, when taken with the number of waste packages, defines the total inventory associated with the waste stream. This inventory is applied during the post-closure assessment and some aspects of operational safety assessment.
- A bounding (maximum) inventory for the waste package for each package type. This inventory is assessed during the transport safety assessment and certain aspects of the operational safety assessment, where individual waste packages are considered.

The UK HPR1000 radionuclide-related data for the average and maximum ILW packages are given in Table B2. For assessment purposes operational waste streams are transported to a GDF at 1 year after arising, except ICIAs, which are transported at 10 years after arising. Decommissioning waste streams are transported to a GDF at 15 years after the assumed reactor operation period. For planning purposes, the DSSC assumes that for wastes arising from new build is emplaced between years 2100 and 2140 for operational ILW; and between years 2145 and 2190 for spent fuel. These emplacement date assumptions do not affect the calculation of the radionuclide inventories used for this GDA disposability assessment.

GNSL provided radionuclide inventories containing the concentration of most of the key radionuclides. These datasets were 'enhanced' for all waste streams except the concrete, to include the 112 radionuclides considered by RWM to be significant for radioactive waste management. Different enhancement approaches were used for each type of material (resins, cartridges, concentrates, sludges, ICIAs, RPV, RPVI). For enhancements, the UK IGD provides useful comparators for equivalent UK HPR1000 waste streams, such as, the operational Sizewell B PWR (specifically resins and filters), as well as operational and decommissioning arisings from previous GDA disposability assessments (namely, the AP1000 [13] and the EPR [12] reactors). GNSL also provided some information on the material properties and chemical characteristics of the wastes. When appropriate, enhancements were also made with inventories produced using the RWM Generic LWR Fuel Inventory spreadsheet (which is based on a computer code for nuclide inventory calculations) which allows the calculation of radionuclide inventories arising from typical irradiations in PWRs reactors .

Resins

The resins comprise of small porous beads, typically between 0.42 mm and 1.2 mm diameter, based on a "cross-linked polystyrene matrix". The beads are a mixture of anion and cation ion exchanger materials that are used to selectively remove certain anions and from solution, the resin beds can also trap particulates. GNSL anticipate the main chemical constituents to be Cl^-, F^-, Li^+, Ca^{2+}, Al^{3+} and SO_4^{2-} ions.

GNSL provided an average and maximum inventory containing data for 35 radionuclides. The submitted inventories were compared with data from similar waste streams in the IGD (namely, AP1000 and EPR) and found to be generally consistent.

The submitted average inventories were enhanced by taking the geometric mean of the (non-zero) average specific activities for the EPR and AP1000 resins, if values were higher than the submitted specific activity, then it was used instead of the submitted value. The enhanced specific activities were multiplied by the mass of material per package to get the average-package inventory at discharge. The same procedure was applied to the respective maximum specific activities.

The average package inventory was calculated by summing the enhanced average inventories discharged at yearly intervals (4 drums), from the start of operation for 60 years, and then dividing by the total number of packages (240). The maximum package was calculated for the maximum-activity resins, discharged at end of life (final year of operation). The radiological data for the average and maximum packages was provided one year after the end of reactor operation.

Cartridges

Filter cartridges comprise of stainless supports with glass fibres and some organic materials (i.e. cellulose). The filters are designed to remove particulate material, which could include activated corrosion products and fragments of fuel.

GNSL provided an average and maximum inventory containing data for 37 radionuclides. The submission was mostly consistent with the data from previous GDA disposability assessments (AP1000 and EPR).

The submitted average and maximum inventories were enhanced as described for the resins. The average package inventory was calculated by summing the enhanced average inventories discharged at yearly intervals (22 filters, two boxes), from the start of operation for 60 years, and then dividing by the total number of packages (120). The maximum package was calculated as the inventory of 11 filters cartridges discharged at end of life (final year of operation). The radiological data for average and maximum packages was provided one year after the end of reactor operation.

Concentrates

The chemical composition of concentrates comprises of Fe, Ni, Ca, Mg, B, Zn, Si; and Na^+, K^+, Cl^-, SO_4^{2-}, HPO_4^{2-} ions with a density of less than 1.2 kg L^{-1}. The maximum concentration of boron (assume to be present as boric acid, H_3BO_3) is 40,000 ppm. The chemical composition (by mass) is similar to other PWRs. The activity in the concentrates is likely to arise from materials in the reactor that have been activated (e.g. steel corrosion products collected in the cooling circuit), plus traces of spent fuel from failed fuel rods.

GNSL provided an average and maximum inventory containing data for 34 radionuclides. These compare well against a comparator stream from the IGD (namely EPR) for the top 10 radionuclides.

Inventories were compared with LWR fingerprints for spent fuel (UOx LWR medium burnup (50 GWd/tU), scaled on Cs137) and activated type 304 steel (UOx LWR medium burnup, scaled on Co60). Inventories were also compared against a comparator EPR stream in the IGD. Gaps in the radiological inventory were filled and if the comparator specific activities were higher than the submitted specific activity, then it was used instead of the submitted value.

The average package inventory was calculated by summing the enhanced average inventories discharged at yearly intervals (approximately 3 drums per year), from the start of operation for 60 years, and then dividing by the total number of packages (190). The maximum package was calculated as the inventory of (1 drum) discharged at end of life (final year of operation). The radiological data for average and maximum packages was provided one year after the end of reactor operation.

Sludges

Sludges comprise of 80 % water with a density of 1.4 kg/L. The chemical composition of sludges is anticipated to be typically Fe, Ni, Cr, Ca, Mg, B, Zn, Si; and Na^+, K^+, F^-, Cl^-, SO_4^{2-}, NO_3^-, HPO_4^{2-} ions

GNSL provided an average and maximum inventory containing data for 27 radionuclides. Inventories were compared against a comparator stream in the IGD (namely, EPR) and the specific activities of the submitted activation products were found to agree reasonably well. Gaps in the radiological inventory were filled and if the comparators specific activities were higher than the submitted specific activity, then it was used instead of the submitted value.

The average package inventory was calculated by summing the enhanced average inventories discharged at yearly intervals, from the start of operation for 60 years, and then dividing by the total number of packages (13). The maximum package was calculated from the enhanced specific activity for the final five years of arisings which generate approximately one package of sludge. The radiological data for average and maximum packages was provided one year after end of reactor operation.

ICIAs

The ICIAs arise from equipment used for measuring temperature, pressure, and neutron flux in the reactor core of UK HPR1000. Three types of ICIAs are distinguished: types (i) and (ii) are neutron flux and temperature measurement assemblies; type (iii) are reactor pressure vessel water level measurement assemblies.

ICIAs comprise mainly of stainless steel and small quantities of alumina ceramic and other metals. GNSL provided an average and maximum inventory containing data for 84 radionuclides. The activities in the type (iii) ICIAs are lower than those in the type (i) and (ii) ICIAs by around four orders of magnitude, which indicates much lower irradiation levels. The submitted average inventory were compared using RWM Generic LWR Fuel Inventory spreadsheet calculations of ICIA materials scaled to Ni63. The LWR fingerprints showed good agreement with submitted radionuclides. Gaps in the radiological inventory were filled. If the submission appeared to be reasonable (being more than half of the corresponding LWR Fuel Inventory spreadsheet calculations estimate), then the submitted value was adopted, if not, the RWM calculated values were adopted.

The average package was based on the summed arising for each year, from the start of operation for 60 years, divided by the total number of packages (75). The radionuclide inventory for the maximum package was based on the inventory for eight type (i&ii) ICIAs discharged at end of reactor operation. The radiological data for average and maximum packages was provided 10 years after end of reactor operation.

Concrete

For the concrete the overall activities are low and are unlikely to challenge the safety limits, therefore, radionuclide activities in this stream have not been enhanced for this stage of assessment. The average and maximum submitted inventories were checked against submitted source data for irradiated concrete from primary shielding and the reactor pit. The specific activity in the maximum package is very similar to that in the innermost annulus of the primary shield (more heavily activated area), and the activity in the average package is very similar to that in the Reactor Pit concrete. There are currently no comparator decommissioning concrete stream in the IGD but the submitted data is considered reasonable.

RPV

RPV wastes comprise of activated material arising from the dismantling of the RPV. The RPV shell is 22 cm thick and made from 16 MND5 (a ferritic carbon steel); the cladding materials (0.7 cm thick) comprises of 309L and 308L stainless steels. The assumed irradiation time is 60 years and the total mass of RPV waste expected is ~402.7 t, of which ~389 t is RPV shell and ~13.7 t is RPV cladding.

GNSL provided an average and maximum inventory containing data for 11 radionuclides. Inventories were compared against a comparator stream in the IGD. The activities of Ni63, Fe55, Co60, Mo93, Tc99 and Mn54 were found to be comparable. For Nb93m and Ni59 the submitted HPR1000 data are rather lower than the EPR and AP1000 data, and for C14, Nb94 and Nb91 the submitted HPR1000 data are many orders of magnitude lower.

Submitted inventories for the average and maximum package were enhanced based on the geometric mean of EPR and APR1000 (15 year-cooled with 23.09 t of steel per package). Gaps in the radiological inventory were filled and if any of the comparator values were higher than the submitted specific activity (e.g. C14, Nb94, Nb91 etc), then it was used instead of the submitted value.

RPVI

The RPVI waste stream comprises mainly of the activated material arising from the dismantling of the RPVI. The RPVI is mostly composed of 304NG (Nuclear Grade stainless steel) with a controlled nitrogen content. The maximum thickness of RPVI (spring and plates) is about 125 mm, other components such as flanges have thickness 30 mm to 70 mm. The minimum thickness of RPVI (some of the tubes) is about 2 mm.

The submission gives 15-year-cooled activities for average and maximum packages, but for only a limited number of radionuclides. Inventories were compared against comparator streams in the IGD and were found to be comparable for key radionuclides submitted (i.e. Ni63, Co60, Fe55, Ni59 and C14). Submitted inventories for the average and maximum package were enhanced based on the geometric mean of EPR and AP1000 (15 year-cooled with 7.02 t of steel per package). Gaps in the radiological inventory were filled and if any of the comparator values were higher than the submitted specific activity, then it was used instead of the submitted value.

Table B2 Summary of UK HPR1000 ILW data for average (Av) and maximum (Max) waste packages and dose rate outside transport package

Identifier	Waste Package Gross Mass (Kg)	Waste package Alpha Activity (TBq)		Waste Package Beta/ Gamma Activity (TBq)	Waste package A_2 Content	Waste Package Heat Output (Watts)	Transport Package Dose rate (mSv/h)[4]
Resins	6047	Av	2.30E-05	1.07E-01	1.13E-01	8.81E-03	8.64E-06
		Max	2.88E-04	4.68E+00	5.29E+00	5.51E-01	3.91E-04
Cartridges	5588	Av	1.07E-03	5.72E-01	1.64E+00	6.49E-02	7.48E-05
		Max	3.90E-03	1.74E+01	3.30E+01	2.61E+00	1.74E-03
Concentrates	1095	Av	4.97E-06	1.47E-03	5.19E-03	9.16E-05	2.22E-03
		Max	4.48E-05	1.03E-02	4.09E-02	1.51E-03	3.37E-02
Sludges	1095	Av	5.52E-06	3.41E-03	7.27E-03	3.47E-04	1.96E-06
		Max	7.27E-05	2.71E-02	8.62E-02	3.91E-03	2.14E-05
ICIA	8573	Av	4.41E-05	1.10E+01	1.66E+01	2.75E+00	1.54E-01 (0 mm)
							4.42E-05 (120 mm)
		Max	8.93E-05	9.70E+01	1.80E+02	2.98E+01	1.67E+00 (0 mm)
							4.81E-04 (120 mm)
Concrete	47,900	Av	-	6.97E-01	3.49E-02	2.34E-02	2.79E-05
		Max	-	9.94E-01	4.97E-02	3.34E-02	4.00E-05
RPV	60,300	Av	5.28E-05	5.98E+00	3.68E+00	5.94E-01	3.24E+00
		Max	5.28E-05	8.83E+00	6.00E+00	9.75E-01	5.36E+00
RPVI	11,820	Av	7.37E-02	5.89E+03	2.36E+03	3.69E+02	2.28E-01
		Max	1.94E-01	1.69E+04	8.15E+03	1.29E+03	8.03E-01

[4] Robust Shielded Drum with 150 mm steel shielding is currently not an available package within RWM assessment toolkit, therefore, 120 mm Pb and 0 mm Pb shielding was assessed as a comparator for dose only. The dose rate refers to that 1m outside transport container (SWTC-150, SWTC-285, SWTC-70). For PRV and concrete waste streams, the dose rates are 1m outside of a 4 m Box with 100-mm concrete shielding.

B4 Description of Spent Fuel, Non-Fuel Core Components, Packaging Assumptions, and Package Numbers and Characteristics

B4.1 Description of Spent Fuel and Non-Fuel Core Components Packaged with Spent Fuel

The reactor core of a UK HPR1000 comprises of RPVI, fuel assemblies and NFCC (ICIAs, SCCAs, RCCAs). The ICIAs and RPVI will be managed as ILW and are discussed above in Section B3. The SCCAs waste stream comprises of 3 Primary Neutron Source Assemblies, 9 Secondary Neutron Source Assemblies and 318 Thimble Plug Assemblies. The RCCAs waste stream consists of 224 'black' rod assemblies, containing strong neutron absorbers and 48 'grey' rod assemblies which contain strong neutron absorbers rods and less-absorbing stainless steel rods.

There are 72 fuel assemblies in the reactor core during operation. The UK HPR1000 is expected to use the Framatome AFA 3G™AA fuel assembly [17]. This assembly consists of up to 264 fuel rods supported by an orthogonal structure with a 17x17 square array. This type of fuel assembly is widely used for PWRs worldwide. The skeleton consists of a top nozzle and bottom nozzle, 24 guide thimbles, 1 instrumentation tube, 8 structural grids (6 of them being mixing grids), and 3 mid-span mixing grids. The instrumentation tube is located in the centre and provides a channel for insertion of an in-core neutron detector. The guide thimbles provide channels for insertion of different types of core components (SCCA or RCCA) whose type depends on the position of the particular fuel assembly in the core [17]. The fuel rods are loaded into the skeleton to form the fuel assembly, in such a way that there is an axial clearance between the fuel rod ends and the top and bottom nozzles, in order to accommodate the differential elongation of the skeleton and the fuel rods during operation.

Fuel assemblies differ in the enrichment of U235 and the number of uranium rods (UO_2) (and gadolinium doped uranium rods (UO_2-Gd_2O_3) if used). The initial HPR1000 core has an average enrichment ranging from approximately 1.80 wt% U-235 to approximately 3.10 wt% U235 for cycle lengths ranging from 1 to 3 years. For the following equilibrium cycle, the HPR1000 reload fuel assemblies have an enrichment of 4.45 wt% U-235. The GDA disposability assessment has assumed that all fuel assemblies contain UO_2 rods only and they have an enrichment of 4.45 wt% U-235. The maximum length of the fuel assembly is 4060.2 mm excluding the top of the NFCC. Other dimensional, mass and material information for fuel assemblies are provided in Table B3 and the estimates of materials breakdown are shown in Table B4.

Figure B5 Example of a typical PWR fuel assembly and RCCA

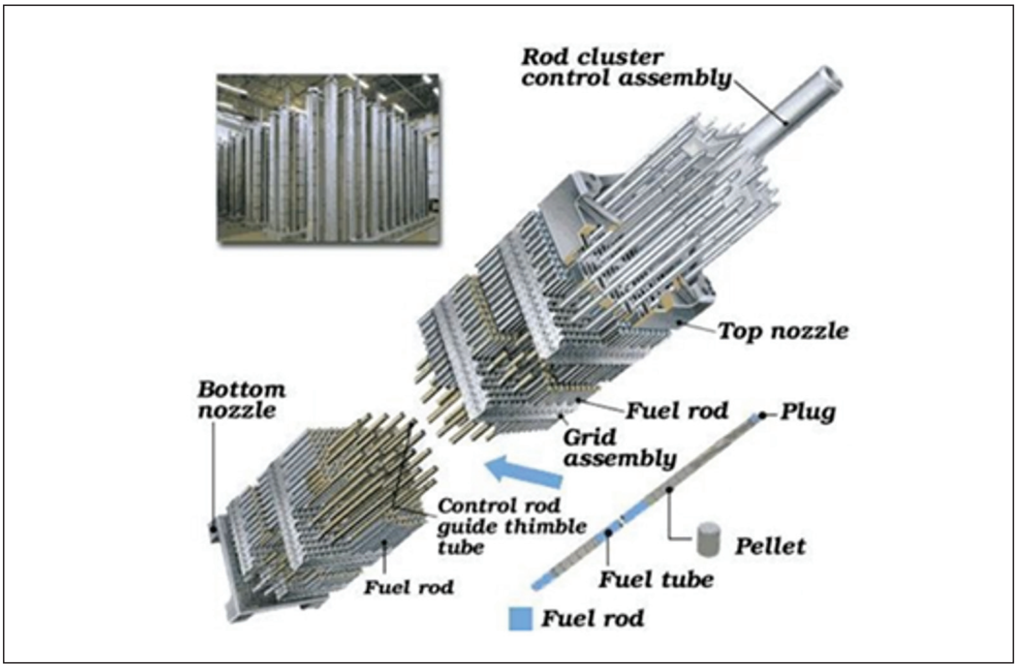


Table B3 Dimensional information for UK HPR1000 fuel assemblies

Fuel Assembly	
External maximum section (mm x mm)	214 x 214
Maximum length (mm)	4060
Maximum mass (kg)	668
Uranium Oxide mass (kg)	522
Number of fuel rods	264

Table B4 Estimates of materials breakdown for one UK HPR1000 fuel assembly

Material Component of Fuel Assembly[5]	Mass per Assembly (kg)
UO_2	522
$M5_{Framatome}$	129
AISI 302	45.8
AISI 304L	3.07
AISI 660	1.60
718 alloy	3.90
304L	1.32
Total	**668**

[5] *Fuel assemblies may contain gadolinium doped fuel rods (UO_2-Gd_2O_3).*

B4.2 Spent Fuel Packaging Assumptions

The packaging assumptions for UK HPR1000 spent fuel [18] are based on concepts developed by RWM to date [19]. Under these concepts, spent fuel would be over-packed into durable disposal containers manufactured from suitable materials, which would support long-term containment for the radionuclides contained within the spent fuel (Figure B6). Although the container material remains to be confirmed, the assessment has considered the potential performance of copper (Variant 1) and steel (Variant 2) containers. The Variant 1 container is fabricated from copper, with a cast iron insert (i.e. based on the SKB KBS-3 container), for compatibility with the needs of a GDF constructed in HSR. Variant 2 container is fabricated from carbon steel (i.e. based on the NAGRA container), for compatibility with the needs of a GDF constructed in LSSR or evaporites.

This GDA disposability assessment has assumed that four UK HPR1000 spent fuel assemblies would be packaged in each disposal container [19]. The disposal concept for spent fuel assumes that fuel assemblies will be loaded into a robust disposal canister, potentially with a length of 5.2 m to accommodate the proposed assemblies (Figure B6). This is a development of the canister envisaged for legacy fuel from Sizewell B PWR and is approximately 0.6 m longer than the current disposal container design. It is assumed that the spent fuel disposal containers required to accommodate new build spent fuel including NFCCs would also be 5.2 m in length.

It is assumed that transport of packaged spent fuel would be undertaken using a DCTC which provides a layer of gamma shielding and neutron shielding material. The DCTC is an RWM preliminary design for transport of legacy spent fuel that will need further development to transport NNB spent fuel. The current concept design has a cavity diameter of 1070 mm and length of 4960 mm [20].

B4.3 Illustrative GDF Design

The disposal container provides one component of the multi-barrier system used to ensure safety following closure of the GDF. In this assessment, the multi-barrier system is assumed to include additional engineered barriers and the geological barrier. The engineered barriers are designed to be compatible with the environment in which the geological disposal facility is constructed. In HSR and LSSR, it is assumed that a bentonite buffer will be emplaced around the waste packages, and engineered plugs will form seals to limit groundwater flow at key locations underground. In evaporite rocks, it is assumed that disposal galleries are backfilled with crushed rock salt, and that seals are placed to limit groundwater flow and radionuclide migration along access ways.

The materials used as part of the engineered barrier system, and the characteristics of the host rock, will affect the thermal criteria used to determine the acceptability of the heat output from waste packages consigned for disposal. In the current generic phase of the programme, generic thermal criteria are used to determine approximate cooling times required before disposal of spent fuel. Different thermal criteria are applied in the illustrative disposal concepts for different host rocks. In HSR, the temperature criterion requires that the temperature of the inner surface of the bentonite buffer should not exceed 100°C. In LSSR, the temperature criterion is that the buffer temperature should not exceed 125°C at its mid-point. In evaporites, the temperature criterion is that the temperature of the host rock should not exceed 200°C. These limits are consistent with criteria used in disposal programmes in other countries.

For the HSR illustrative GDF design, which is considered to be the bounding case, spent fuel containers would be emplaced in deposition holes lined with a buffer made from compacted bentonite, which swells following contact with water (Figure B7). The concept is based on the KBS-3V concept developed by SKB for disposal of spent fuel in Sweden [19].

Figure B6 Illustration of Variant 1 (left) and Variant 2 (right) spent fuel disposal container [18]

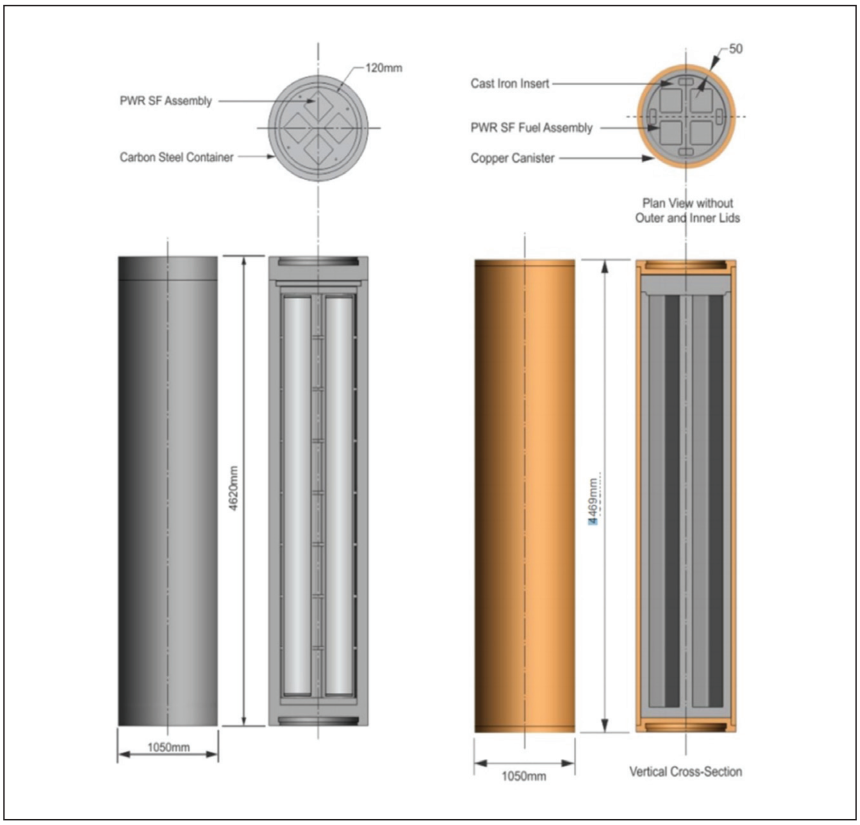
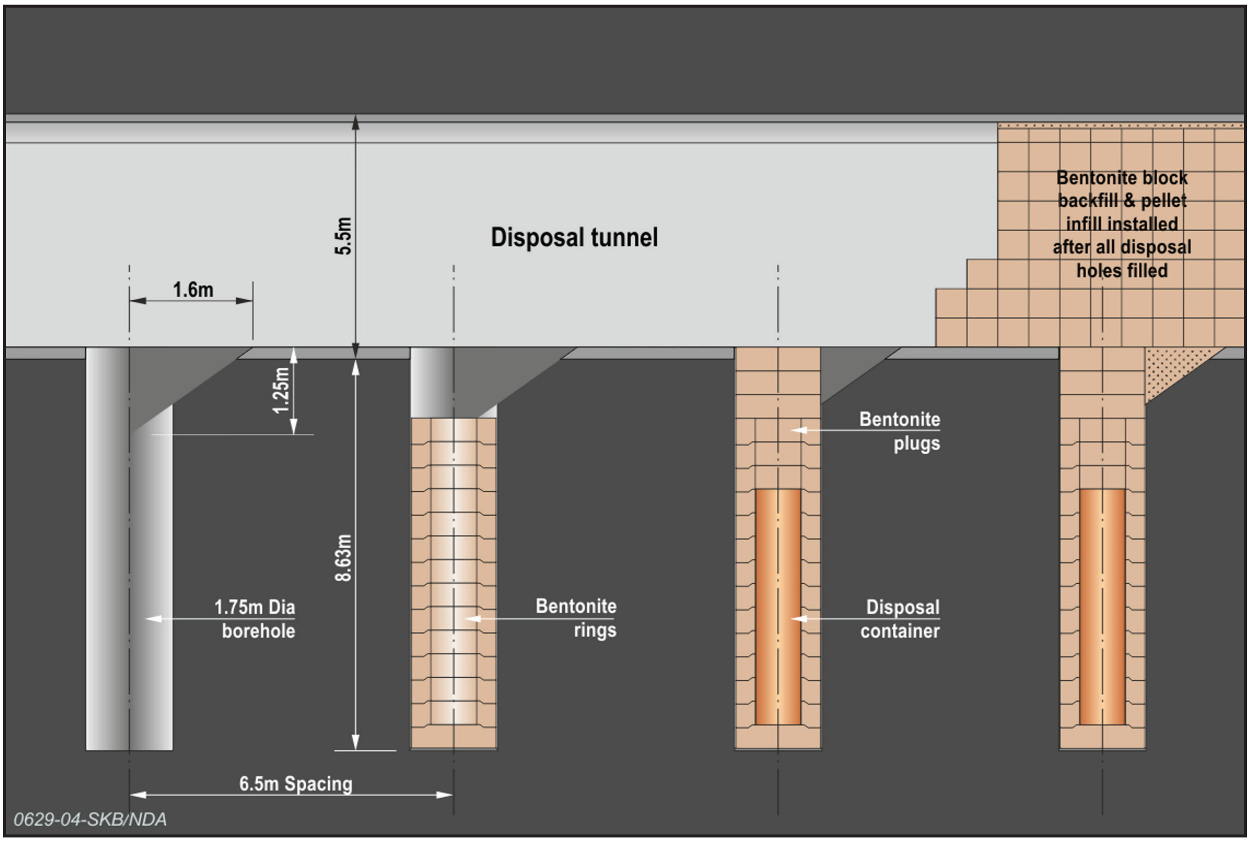


Figure B7 Longitudinal section of a disposal tunnel in higher strength rock illustrating the deposition holes and immediate emplacement of backfill following disposal of spent fuel container [18]



B4.4 Spent Fuel Package Characteristics

GNSL has estimated that a UK HPR1000 would discharge 2985 spent fuel assemblies over its 60-year operational life. This corresponds to 747 disposal containers.

Fuel assemblies differ in the enrichment of U235 and the number of uranium rods (UO_2) and Gd-doped uranium rods (UO_2-Gd_2O_3). Currently there is no indication on the quantity of gadolinium, therefore, Gd was excluded from the assessment inventory. However, it is noted that Gd-doped uranium rods have been assessed for previous GDAs [12,13,14] and no issues were found.

GNSL provided one-year-cooled HPR1000 fuel assembly inventory based on PALM modelling. PALM code is a validated point depletion calculation code developed by CGN for use for the CGN fleet. This code takes information, such as cross section, decay information and fission product yields from a dedicated library, and calculates the composition of structures/components after irradiation by solving the depletion equation. The reliability of PALM on decay heat and source term calculation has been verified and validated for PWRs [21].

The spent fuel assembly inventories were checked by RWM using independent calculations. For non-fuel components (such as fuel rod cladding) inventories were enhanced using GFIT. For the UOx fuel, inventories were enhanced using RWM High Heat Inventory Tool (HHIT), which is based on ORIGEN V6 (computer code system for calculating the buildup, decay, and processing of radioactive material) calculations. The independent calculations resulted in a good match for most of the radionuclides, confirming that the calculations underlying the submission are reliable; however, several radionuclides were absent from the submission data. The submitted inventories were enhanced by scaling fingerprints using the appropriate radionuclide for the non-fuel material (Nb95) and fuel (Cs137). Gaps in the radiological inventory were filled and if the comparators specific activities were higher, then it was used instead of the submitted value.

For the average spent fuel inventory, the total arisings inventories of 1-year-cooled enhanced inventory for 72 average-burnup fuel assemblies discharged at the end of each cycle (i.e. at times of 1½, 3, 4½, 6, … 60 years) from the start of operation were divided by the number of packages (746.25) to obtain lifetime average inventory. The maximum spent fuel inventory is 1-year-cooled enhanced inventory for four maximum fuel assemblies discharged at the end of operation.

In PWRs, control rods and sources are incorporated as part of the fuel assembly and GNSL propose that these waste streams (namely, RCCA and SCCA) are managed alongside spent fuel. The submitted RCCA and SCCA inventories were checked using ORIGEN calculations for AP1000 which has similar types of NFCC. Given that the absorber compositions and/or neutron cross-sections may not be directly comparable, the radionuclide inventory submitted by GNSL were not overridden. However, the submission did not consider trace impurities in the other items that make up the assembly (i.e. the spider and the rod cladding), therefore, resulting gaps in the GNSL inventory have been filled using the AP1000 inventory, scaled using Ni63.

For the average NFCC inventory, the total RCCA and SCCA arisings inventories were divided by 602 to obtain lifetime average inventory. For the maximum NFCC inventory, for each type of NFCC and radionuclide, the highest calculated values were used to create a one-year-cooled 'composite maximum'.

The average and maximum NFCC inventories were added to the corresponding average and maximum spent fuel inventories to produce an average and maximum spent fuel & NFCC packages. The radiological data for average and maximum packages for spent fuel and NFCC was provided 10 years after the end of reactor operation.

The UK HPR1000 spent fuel and NFCC package radionuclide-related data for the average and maximum package are given in Table B5.

Table B5 – Summary of UK HPR1000 spent fuel and NFCC data for average (Av) and maximum (Max) waste packages and dose rate outside transport package

Identifier	Waste Package Gross Mass (Kg)	Waste package Alpha Activity (TBq)		Waste Package Beta/ Gamma Activity (TBq)	Waste package A_2 Content	Waste Package Heat Output (Watts)	Transport Package Dose rate (mSv/h)[6]
Spent Fuel and NFCC	2699	Av	6.51E+02	1.47E+04	6.59E+05	1.56E+03	9.23E-02
		Max	9.68E+02	3.95E+04	1.01E+06	3.64E+03	5.66E-01

[6] *The transport package dose rate refers to 1m outside a DCTC.*

Appendix C - Glossary

Acronym/ abbreviation	Term
ALARA	as low as reasonably achievable
ALARP	as low as reasonably practicable
AP1000	Westinghouse Advanced Pressurized 1000 Reactors
cartridges	spent filter cartridges
CGN	China General Nuclear Power Group
concrete	decommissioning concrete
DCTC	disposal container transport container
EDF	Électricité de France
EPR	EDF European Pressurised Water Reactor
GDA	generic design assessment
GDF	geological disposal facility
DSSC	generic disposal system safety case
GFIT	RWM generic fuel inventory toolkit
HAW	higher-activity wastes
HHIT	RWM high heat inventory tool
HPR1000	Hua-Long Pressurised Reactor
HSR	higher strength rock
IAEA	International Atomic Energy Agency
ICIAs	in-core instrumentation assemblies
IGD	inventory for geological disposal
ILW	intermediate level waste
IP-2	industrial package Type 2
LoC	letter of compliance
LSSR	lower strength sedimentary rock
NFCC	non-fuel core components
PWRs	pressurised water reactors
RCCAs	rod cluster control assemblies
Resin	spent ion exchange resins
RPV	reactor pressure vessel
RPVII	reactor pressure vessel internals
RWM	Radioactive Waste Management Limited
SCCAs	stationary core component assemblies
SWTCs	standard waste transport containers

Term	Definition
A2	A unit of activity (expressed in TBq) of a specified radionuclide linked to possible exposure pathways and defined by the IAEA Transport Regulations as the maximum activity of radioactive material that can be transported in a Type A transport package without conditions being placed on the form of the material.
activation product	A radionuclide created by the neutron irradiation of a previous non-radioactive material. Typically, this occurs in the structural and moderator materials (e.g. steel and graphite) of nuclear reactors.
activity	The number of atoms of a radioactive substance which decay by nuclear disintegration each second. The SI unit of activity is the Becquerel (Bq).
alpha activity	Alpha activity takes the form of particles (helium nuclei) ejected from a decaying (radioactive) atom. Alpha particles cause ionisation in biological tissue which may lead to damage. The particles have a very short range in air (typically about 5 cm) and alpha particles present in materials that are outside of the body are prevented from doing biological damage by the superficial dead skin cells but become significant if inhaled or swallowed.
becquerel (Bq)	The standard international unit of radioactivity equal to one radioactive decay per second.
Best Available Technique (BAT)	The means an operator uses in the operation of a facility to deliver an optimised outcome, ie to reduce exposures to ALARA. For clarity, BAT are the means (for example plant and processes) the operator uses to control disposals of radioactive waste into the environment.
Best Practicable Means (BPM)	A qualification used by the Scottish Environment Protection Agency and NIEA in certain conditions of RSA 93 Authorisations, which require Authorisation holders to: i) minimise the activity of radioactive waste generated, ii) minimise the activity of gaseous and aqueous radioactive waste discharged to the environment, iii) minimise the volume of radioactive waste transferred to other premises, and iv) dispose of radioactive wastes in such a way as to minimise the radiological effects on the public. In determining whether particular means are the "best practicable", the Authorisation Holder is not required to incur expenditure whether in money, time or trouble which is, or is likely to be, grossly disproportionate to the benefits to be derived from, or likely to be derived from, or the efficacy of, or likely efficacy of, employing them, the benefits or results produced being, or likely to be, insignificant in relation to the expenditure. If the operator is using BPM in relation to the above requirements, radiation risks to the public will be as low as reasonably achievable, economic and social factors being taken into consideration (ALARA).

Term	Definition
Best Practicable Environmental Option (BPEO)	The outcome of a systematic and consultative decision-making procedure which emphasises the protection and conservation of the environment across land, air and water. The BPEO approach establishes, for a given set of objectives, the option that provides the most benefit or least damage to the environment as a whole, at acceptable cost, in the long-term as well as in the short term.
beta activity	Beta activity takes the form of particles (electrons) emitted during radioactive decay from the nucleus of an atom.
buffer	An engineered barrier that protects the waste package and limits the migration of radionuclides following their release from a waste package.
canister	The vessel in which a HLW/spent fuel/Pu/HEU wasteform is placed.
containment	The key long-term safety functions required for a GDF are isolation and containment. By containment we mean retaining the radioactivity from the wastes within various parts of the disposal facility for as long as required to achieve safety.
corrosion	Progressive surface dissolution of a material.
Criticality safety	Criticality safety is defined as protection against the consequences of an inadvertent nuclear chain reaction, preferably by prevention of the chain reaction.
decommissioning waste	Radioactive waste produced during operations involved in the decommissioning of a nuclear facility (as distinct from operational waste).
design requirements	The design requirements describe what the design systems (and sub-systems) must do, how well the systems must perform and any constraints within which the design systems should operate. Each design requirement should be traceable to a source requirement within the Disposal System Specification. The Design Requirements will include safety functions.
disposability assessment	The process by which proposals for the production of waste packages are analysed for compatibility with all stages of waste management. The outcome of a disposability assessment is an Assessment Report, detailing the results of the analysis and providing advice on the proposals. Where possible, the outcome includes endorsement by issue of a Letter of Compliance.
disposal	In the context of solid waste, disposal is the placement of waste in a suitable facility without intent to retrieve it at a later date.
disposal concept	A high level description of the engineered and natural barriers required to ensure that the radioactivity in the wastes is sufficiently contained so that it will not be released back to the surface in unacceptable amounts that may cause harm to people and the environment.

Term	Definition
disposal system safety case (DSSC)	The Disposal System Safety Case is the collection of documentation that together defines the scientific basis for geological disposal and presents the arguments as to why this can be achieved safely.
specification (DSS)	A document produced by RWM to set out the high-level and technical requirements on the RWM's organisational management, site selection and evaluation and GDF design, construction, operation and closure, so that the disposal system can meet its fundamental need.
disposal tunnel	Tunnel in which waste packages are emplaced for disposal. Disposal tunnels typically have a relatively small cross-section.
disposal vault	Underground opening where waste packages are emplaced for disposal. Disposal vaults typically have a relatively large cross-section, the geometry of which will be influenced by the disposal concept and the characteristics of the geological environment.
dose rate	Effective dose per unit time. Typical units of dose rate are sievert/hour (Sv hr-1), millisieverts/hour (mSv hr-1) and sievert/year (Sv yr-1).
engineered barrier system	The combination of the man-made engineered components of a disposal facility, including the waste packages / disposal containers, buffer, backfills and seals.
evaporite	One of three generic host rock types considered by RWM. Evaporites are rocks that have formed as ancient seas and lakes evaporated. They often contain bodies of halite that are potential host rocks for a GDF because they provide a suitably dry environment and are weak and creep easily so that open cracks cannot be sustained.
fissile material	Material which is capable of undergoing fission by interaction with slow neutrons, specifically U-233, U-235, Pu-239, Pu-241 or any combination of these radionuclides.
fission product	A radionuclide produced by nuclear fission.
footprint	A term used in the context of the design to refer either to the area occupied by the surface facilities (surface footprint) or the area of host rock underground required to accept the inventory to be disposed of (underground footprint).
gamma activity	An electromagnetic radiation similar in some respects to visible light, but with higher energy. Gamma rays cause ionisations in biological tissue which may lead to damage. Gamma rays are very penetrating and are attenuated only by shields of dense metal or concrete, perhaps some metres thick, depending on their energy. Their emission during radioactive decay is usually accompanied by particle emission (beta or alpha activity).

Term	Definition
Generic Waste Package Specification (GWPS)	The RWM packaging specifications define the bounding features and performance requirements for waste packages that would be compatible with the anticipated needs for transport to and disposal in a GDF. Formed of a hierarchy of three levels, the top-level GWPS (Level 1) defines the high-level requirements for all waste packages destined for geological disposal (for additional classifications see waste package specification).
geological disposal facility (GDF)	A long-term management option involving the emplacement of radioactive waste in an engineered underground geological disposal facility or repository, where the geology (rock structure) provides a barrier against the escape of radioactivity and there is no intention to retrieve the waste once the facility is closed.
hazardous materials	Materials that can endanger human health if improperly handled. As defined by the Control of Substances Hazardous to Health Regulations, 2002.
higher activity waste (HAW)	Includes the following categories of radioactive waste: high level waste, intermediate level waste, a small fraction of low level waste with a concentration of specific radionuclides sufficient to prevent its disposal as low level waste.
high level waste (HLW)	Waste in which the temperature may rise significantly as a result of their radioactivity, so this factor has to be taken into account in the design of storage or disposal facilities. HLW is produced as a by-product from reprocessing spent fuel from nuclear reactors. HLW typically occurs in liquid form and a process called 'vitrification' converts the liquid HLW into a solid product.
higher strength rock (HSR)	One of three generic host rock types considered by RWM. Higher strength rocks, which may be igneous, metamorphic or older sedimentary rocks, have a low matrix porosity and low permeability, with the majority of any groundwater movement confined to fractures within the rock mass. *Typically crystalline igneous and metamorphic rocks or geologically older sedimentary rocks where any fluid movement is predominantly through discontinuities.*
high heat generating waste (HHGW)	A term developed by RWM to describe all the materials in the inventory for disposal where heat has to be taken into account in the design of storage and disposal facilities. HHGW comprises spent fuel from existing and future power stations, and High Level Waste from spent fuel reprocessing.
illustrative design	An example design for a geological disposal system, developed by RWM for illustrative purposes, drawing on work done in the UK and in international radioactive waste disposal programmes.

Term	Definition
illustrative disposal concept	An example disposal concept, developed by RWM for illustrative purposes, drawing on work done in the UK and in international radioactive waste disposal programmes.
immobilisation	A process by which the potential for the migration or dispersion of the radioactivity present in a material is reduced. The term applies to several components of the engineered barrier system, i.e. the wasteform, the cement buffer and the backfill.
industrial package (IP)	A category of transport package, defined by the IAEA Transport Regulations for the transport of radioactive materials with low specific activities.
intermediate level waste (ILW)	Wastes exceeding the upper boundaries for LLW, but which do not need heat to be taken into account in the design of storage or disposal facilities.
Inventory for disposal	The specific types of higher activity radioactive waste (and nuclear materials that could be declared as waste) which will be disposed of in a geological disposal facility.
Letter of Compliance (LoC)	A document, prepared by RWM, that indicates to a waste packager that a proposed waste package is compliant with the relevant packaging criteria and disposal safety assessments, and is therefore deemed to be compatible with the requirements for storage, transport, handling and disposal.
lower strength sedimentary rock (LSSR)	One of three generic host rock types considered by RWM. Lower strength sedimentary rocks are fine-grained, sedimentary rocks with a high content of clay minerals that provides their low permeability and are mechanically weak, so that open fractures cannot be sustained. They will be interlayered with other sedimentary rock types.
low heat generating waste (LHGW)	A term developed by RWM to describe materials in the inventory for disposal which do not generate sufficient heat for this to be taken into account in the design of storage and disposal facilities. LHGW comprises intermediate Level Waste arising from operating and decommissioning of reactors and other nuclear facilities, together with a small amount of Low Level Waste unsuitable for near surface disposal, and stocks of depleted, natural and low-enriched uranium.
low level waste (LLW)	Wastes having a radioactive content not exceeding 4GBq (gigabecquerels) per tonne of alpha, or 12GBq per tonne of beta/gamma activity.
new build	General term for any new nuclear power station.

Term	Definition
Nuclear Decommissioning Authority (NDA)	An executive non-departmental public body created through the Energy Act 2004 to ensure the safe and efficient clean-up of the UK's nuclear legacy.
operational waste	Radioactive waste produced during the normal operations of a nuclear facility (as distinct from decommissioning waste).
optioneering	A structured evaluation of options in support of decision-making. Such an evaluation may take the form of an option study that collates information on the options and the different attributes that will influence the decision to be made and may also consider how the decision is influenced by different value judgements.
post-closure period (of a disposal facility)	The period following sealing and closure of a facility.
pressurised water reactor (PWR)	Reactor type using ordinary water under high pressure as a coolant and neutron moderator. PWRs are widely used throughout the world for electricity generation. The Sizewell B reactor in Suffolk is of this design.
radioactive decay	Radioactive decay, also known as nuclear decay or radioactivity, is the process by which the nucleus of an unstable atom loses energy by emitting radiation, including alpha particles, beta particles, gamma rays and conversion electrons. A material that spontaneously emits such radiation is considered radioactive. The rate at which atoms disintegrate is measured in becquerels.
Radioactive Waste Management Limited (RWM)	A wholly owned subsidiary company of the NDA, which commenced trading on the 1st of April 2014, responsible for implementing a safe, sustainable, publicly acceptable geological disposal programme. Ultimately, RWM will evolve under the NDA into the organisation responsible for the delivery of the GDF. Ownership of this organisation can then be opened up to competition, in due course, in line with other NDA sites.
shielding	Shielding is the protective use of materials to reduce the dose rate outside of the shielding material. The amount of shielding required to ensure that the dose rate is ALARP will therefore depend on the type of radiation, the activity of the source, and on the dose rate that is acceptable outside the shielding material.
spent fuel	Nuclear fuel removed from a reactor following irradiation that is no longer usable in its present form because of depletion of fissile material, poison build-up or radiation damage.
Transport Assessment (TA)	An assessment of the potential transport effects of a proposed project.

Term	Definition
transport container	A reusable container into which waste packages are placed for transport, the whole assembly then being referred to as a transport package.
transport package	The complete assembly of the radioactive material and its outer packaging, as presented for transport.
transport regulations	The IAEA Regulations for the Safe Transport of Radioactive Material and/or those regulations as transposed into an EU Directive, and in turn into regulations that apply within the UK. The generic term 'Transport Regulations' can refer to any or all of these, since the essential wording is identical in all cases.
waste container	The vessel into which a wasteform manufactured from certain waste types (i.e. LHGW) is placed to form a waste package suitable for handling, transport, storage and disposal.
wasteform	The waste in the physical and chemical form in which it will be disposed of, including any conditioning media and container furniture (i.e. in-drum mixing devices, dewatering tubes etc) but not including the waste container itself or any added inactive capping material.
waste package	The product of waste conditioning that includes the wasteform and any container(s) and internal barriers (e.g. absorbing materials and liner), as prepared in accordance with requirements for handling, transport, storage and/or disposal.
Waste Package Specification (WPS)	The RWM packaging specifications define the bounding features and performance requirements for waste packages that would be compatible with the anticipated needs for transport to and disposal in a GDF. Formed of a hierarchy of three levels, each WPS (Level 3 and the most detailed of the specifications) defines the requirements for the transport to and geological disposal of waste packages manufactured using a standardised design of waste container that have been shown to be compatible with RWM's current plans for geological disposal for the packaging of a specific category of waste. These can sometimes be generic.

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