Geological Disposal

Generic Operational Safety Assessment: Volume 2 - Normal operations operator dose assessment

December 2010
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Executive summary

We, the Radioactive Waste Management Directorate of the Nuclear Decommissioning Authority, have been charged with implementing the UK Government’s policy for the long-term management of higher activity radioactive waste by planning, building and operating a geological disposal facility (GDF). The UK has accumulated a legacy of radioactive waste from electricity generation, defence activities and other industrial, medical, agricultural and research activities. Radioactive wastes continue to be produced from these activities. Some of these wastes would remain hazardous for hundreds of thousands of years.

The Disposal System Safety Case (DSSC) considers the safety of radioactive waste transport, the safety of the construction and operation of the facility, and the safety of the facility in the very long term, after it has been sealed and closed. The DSSC is in the early stages of development, because the site and design have not yet been chosen. We call it a ‘generic’ safety case, and the strategy to demonstrate safety is also termed ‘generic’ because it must cover a range of possible disposal environments and facility designs. Nevertheless, this work builds on more than 25 years of experience studying geological disposal and undertaking safety assessments in the UK. It also draws on the extensive body of knowledge and experience in other countries gained through overseas radioactive waste management programmes.

The generic DSSC addresses the following:

- transporting the waste to a GDF – the safety arguments and assessment of this are presented in the generic Transport Safety Case (TSC)
- construction of and emplacement of waste within a GDF, subsequent storage and eventual backfilling, decommissioning and closure – presented in the generic Operational Safety Case (OSC)
- the environmental safety of a GDF during the operational period and after closure of the facility - presented in the generic Environmental Safety Case (ESC).

The OSC comprises a Main Report and four volumes of Safety Assessment:

- Volume 1 - Construction and non-radiological safety assessment
- Volume 2 - Normal operations operator dose assessment
- Volume 3 - Accident safety assessment
- Volume 4 - Criticality safety assessment

This report presents the predicted illustrative doses to workers as a consequence of routine operations at a GDF for three illustrative geologies. The geologies considered are:

- higher strength rock
- lower strength sedimentary rock
- evaporite

The report builds upon and develops an earlier safety case (published in 2003) that is referred to as the Generic Operational Safety Assessment (GOSA). Updates have been made to reflect current thinking on operator exposure times and to include the handling and disposal of packages containing high level waste (HLW), spent fuel (SF), Plutonium and Uranium. The assessment divides the GDF into areas and the annual doses to workers in these areas are calculated. The calculations take account of the tasks performed in each area, the estimated number of packages in the area and the occupancy of the area required for operators to perform the tasks. Doses for handling and monitoring operations requiring operators to work in close proximity to transport packages were taken from similar operations during transport of waste packages. Data and methodologies from earlier safety
assessments were also employed to assess representative but bounding doses for work in some other areas of the GDF.

For a number of operations carried out at the surface, some mitigatory measures will require to be included in the developed design to maintain individual annual doses below the design target. These mitigations will include carrying out certain operations, such as uncoupling of rail wagons remotely and certain operations, such as monitoring of transport packages, away from areas where numbers of packages will be temporarily stored since such areas will have relatively high ambient radiation levels. In addition, access to areas where numbers of packages will be temporarily stored, such as the rail sidings and the trailer park will be restricted because of their elevated background radiation levels. With these mitigations in place, operator doses for surface operations are predicted to be below the design target. Annual doses in surface areas will be independent of host geology.

Underground, operations in one particular area – the inlet cell operating area – were assessed as requiring further mitigation to meet the design target. The dose in this area will be from transport packages containing unshielded waste packages stored in the buffer storage area. In this case, the mitigation is likely to be an increase in the shielding between the two areas. The next most significant exposures are assessed to be those occurring during emplacement of shielded waste packages in their disposal vault. While these are not assessed to require further mitigation to meet the design target, it is possible that future assessments will find some additional mitigatory measures to be reasonably practicable to implement. An example of simple measures which could be put in place are provision of training for stacker truck drivers in an inactive area in order to reduce the time spent in close vicinity to the working face in the disposal vault. It may well be that this would be more effective than, for example, the provision of shielding on the driver’s cab which could potentially restrict visibility and thereby increase exposure times and doses. Doses incurred in the underground disposal area (rail receipt area, buffer store and disposal vault) for shielded packages will be dependent on the host geology. This is because the ambient radiation levels will be dependent on the number of packages in the front rank of emplaced packages. This number will be lower for the evaporite and sedimentary rock geologies in which vault cross sections would have to be smaller. In these cases, doses are assessed to be significantly lower than for the reference case.

In addition to the careful design of working practices, management arrangements and procedures, routine exposure will be limited through the provision of appropriate shielding, restriction of access to high background areas and design for remote operation to the degree that is reasonably practicable. It is therefore concluded that there is confidence that the design targets for all workers on-site will be met.

Future work on normal operations dose to GDF operators will extend the assessment to those areas not directly involved in the processing of waste packages and to groups of operators who may spend time working in a number of different areas. Further work will also be required on quantification of potential doses from inhalation of airborne contamination emanating from packages and from inhalation of natural radioactivity emanating from the host rock.
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<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AGR</td>
<td>Advanced Gas-cooled Reactor</td>
</tr>
<tr>
<td>ALARP</td>
<td>As Low As Reasonably Practicable</td>
</tr>
<tr>
<td>CoRWM</td>
<td>Committee on Radioactive Waste Management</td>
</tr>
<tr>
<td>DCTC</td>
<td>Disposal Canister Transport Container</td>
</tr>
<tr>
<td>DNLEU</td>
<td>depleted, natural and low enriched uranium</td>
</tr>
<tr>
<td>DSSC</td>
<td>Disposal System Safety Case</td>
</tr>
<tr>
<td>DU</td>
<td>depleted uranium</td>
</tr>
<tr>
<td>EA</td>
<td>Environment Agency</td>
</tr>
<tr>
<td>ESC</td>
<td>Environmental Safety Case</td>
</tr>
<tr>
<td>GDF</td>
<td>Geological Disposal Facility</td>
</tr>
<tr>
<td>GRA</td>
<td>guidance on requirements for authorisation</td>
</tr>
<tr>
<td>HEPA</td>
<td>High Efficiency Particulate in Air</td>
</tr>
<tr>
<td>HEU</td>
<td>high enriched uranium</td>
</tr>
<tr>
<td>HLW</td>
<td>high level waste</td>
</tr>
<tr>
<td>HSE</td>
<td>Health and Safety Executive</td>
</tr>
<tr>
<td>IAEA</td>
<td>International Atomic Energy Agency</td>
</tr>
<tr>
<td>ILW</td>
<td>intermediate level waste</td>
</tr>
<tr>
<td>IRR 99</td>
<td>Ionising Radiations Regulations 1999</td>
</tr>
<tr>
<td>LLW</td>
<td>low level waste</td>
</tr>
<tr>
<td>MBGWS</td>
<td>Miscellaneous Beta Gamma Waste Store</td>
</tr>
<tr>
<td>MRWS</td>
<td>Managing Radioactive Waste Safely</td>
</tr>
<tr>
<td>NDA</td>
<td>Nuclear Decommissioning Authority</td>
</tr>
<tr>
<td>NIA 65</td>
<td>Nuclear Installations Act 1965 (as amended)</td>
</tr>
<tr>
<td>NIEA</td>
<td>Northern Ireland Environment Agency</td>
</tr>
<tr>
<td>NII</td>
<td>Nuclear Installations Inspectorate</td>
</tr>
<tr>
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<td>NII safety assessment principles</td>
</tr>
<tr>
<td>OSC</td>
<td>Operational Safety Case</td>
</tr>
<tr>
<td>RWMD</td>
<td>Radioactive Waste Management Directorate</td>
</tr>
<tr>
<td>SEPA</td>
<td>Scottish Environment Protection Agency</td>
</tr>
<tr>
<td>SF</td>
<td>spent fuel</td>
</tr>
<tr>
<td>SILW</td>
<td>shielded intermediate level waste</td>
</tr>
<tr>
<td>SLC</td>
<td>site licence company</td>
</tr>
<tr>
<td>TSC</td>
<td>Transport Safety Case</td>
</tr>
<tr>
<td>UILW</td>
<td>unshielded intermediate level waste</td>
</tr>
<tr>
<td>WAGR</td>
<td>Windscale Advanced Gas Cooled Reactor</td>
</tr>
</tbody>
</table>
1 Introduction

We, the Nuclear Decommissioning Authority (NDA), have responsibility for implementing a Geological Disposal Facility (GDF) in the UK, supporting the UK Government and devolved administrations in its commitments, as set out in the Managing Radioactive Waste Safely (MRWS) White Paper [1]. The MRWS White Paper includes the stages in a GDF site selection process that would lead to the identification of sites for desk-based studies, followed by surface investigations at candidate sites, and leading ultimately to the identification of a preferred site. The White Paper also defines the materials that may need to be managed through geological disposal. It defines a Baseline Inventory of high level waste (HLW), intermediate level waste (ILW), some low level waste (LLW) unsuitable for near-surface disposal, spent fuel (SF), depleted natural and low-enriched uranium (DNLEU), highly-enriched uranium (HEU) and separated plutonium (Pu). SF, DNLEU, HEU and Pu are not currently considered wastes but may be so in the future. An Upper Inventory is also defined that includes wastes that may arise from new nuclear power stations.

Our Radioactive Waste Management Directorate (RWMD) is working on a programme to implement geological disposal in the UK. In the future, it is envisaged that RWMD will be established as a subsidiary of the NDA responsible for delivery of a GDF. RWMD is currently operating under voluntary scrutiny by our regulators as a “prospective Site Licence Company” (SLC) in order to demonstrate and develop the competences required of a future holder of a regulatory authorisation and nuclear site licence.

We are currently in the first phase of our programme, undertaking preparatory studies, and during this phase we have produced a generic Disposal System Safety Case (DSSC). The generic DSSC explains and assesses the safety and environmental implications of all aspects associated with the geological disposal of higher activity radioactive waste in the UK. The generic DSSC covers three main areas; for each we have prepared a separate safety report:

- transporting the waste to a GDF – the safety arguments and assessment of this are presented in the generic Transport Safety Case (TSC) [2]
- construction of and emplacement of waste within a GDF, subsequent storage and eventual backfilling, decommissioning and closure – presented in the generic Operational Safety Case (OSC) [3]
- the environmental safety of a GDF during the operational period and after its closure - presented in the generic Environmental Safety Case (ESC) [4].

When integrated, the TSC, OSC and ESC, and their supporting documents, comprise the DSSC, an overall statement of the safety of the complete disposal system.

This document, the construction and non-radiological safety assessment, is one component of the generic operational safety case.

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1 Throughout this report, the term UK Government refers to the Department of Energy and Climate Change (DECC), Department for Environment, Food and Rural Affairs (Defra), the Department for Business, Enterprise and Regulatory Reform (BERR), the Welsh Assembly Government and the Department of the Environment Northern Ireland. The Scottish Government does not support geological disposal – it advocates interim near surface, near site storage for higher activity radioactive wastes.
1.1 Disposal System Safety Case

The generic OSC is not site-specific and so we have used illustrative concept examples to examine the safety aspects of a GDF and the radioactive waste packages with respect to both normal operations and potential accidents. The OSC focuses on the main operational phase during which radioactive waste packages will be received on site, transported underground and emplaced in the disposal areas.

The OSC also considers safety issues associated with the construction and commissioning of the above and below ground facilities, including the separation of construction and waste emplacement activities once a GDF becomes operational. Issues relating to possible retrieval of emplaced packages are also discussed.

Operations such as backfilling, closure and decommissioning of the GDF have not been considered in any depth at this stage because there is insufficient design detail to support meaningful analysis. However, since these operations do not involve the physical movement of packages we expect any contribution to overall GDF risk will be small. Our strategy for addressing decommissioning and closure operations within the design is discussed later in this report. As we develop our designs further we will assess the risks posed by these operations in detail.

Similarly, low risk surface facilities, such as those used for monitoring and handling of incoming waste packages, and auxiliary buildings such as laboratories and maintenance facilities, will be assessed when we have more design detail. We will also address the rail and road systems used to transport the waste packages across the site.

The OSC takes over from the Transport Safety Case (TSC) when the package is cleared for loading onto an internal transport vehicle for transfer underground and hands over to the Environmental Safety Case (ESC) following closure. However, the impact of normal operational releases of activity to the public and the environment, at all stages of the GDF lifecycle, is considered in the ESC.

1.2 OSC hierarchy

The OSC is one of a series of documents that will be produced to support our regulatory submissions and to support the dialogue with our stakeholders during the development of a GDF. We use the overarching term Disposal System Safety Case to cover the hierarchy of documentation that provides the evidence to demonstrate that suitable and sufficient arrangements will be in place to ensure the safety of a GDF.

The OSC deals with the safety of construction and operation of a GDF, including waste receipt, emplacement underground, storage and eventual backfilling closure and decommissioning.

The generic OSC Main Report is supported by four volumes of safety assessment:

- Volume 1 Construction and Conventional Safety Assessment [5]
- Volume 2 Normal Operations Operator Dose Assessment (this report)
- Volume 3 Accident Safety Assessment [6]
- Volume 4 Criticality Safety Assessment [7].

1.3 Normal operations operator dose assessment

The location of the GDF in the UK is, at the time of writing of this report, as yet undecided. Government policy states that the site selection process for a GDF will be based upon voluntarism and partnership [1]. As the location has not been specified, there are several
types of geology in which a GDF could be constructed. Three different host rock geologies have been considered in this report. The geologies are defined as follows:

- **higher strength rock** - this would typically comprise crystalline igneous and metamorphic rocks or geologically older sedimentary rocks where any fluid movement is predominantly through discontinuities.
- **lower strength sedimentary rock** - this would typically comprise geologically younger sedimentary rock where any fluid movement is predominantly through the rock matrix.
- **evaporite** - this would typically comprise anhydrite (anhydrous calcium sulphate), halite (rock salt) or other evaporites that were formed from the evaporation of water from water bodies containing dissolved salts.

It should be noted that the term 'host rock' refers only to the rock formation surrounding the area where waste emplacement will occur. Any overlaying rocks are considered to be either of equivalent type to the host rock or a sequence of sedimentary rocks overlaying the host rock formation.

These different host geologies for a GDF will impact on the illustrative conceptual designs of the underground facilities and also the techniques used for some of the emplacement operations. These factors will in turn influence the annual illustrative doses to GDF workers and are explored within this report.

### 1.3.1 Scope of this report

This report covers the methodology and data used to calculate example illustrative doses to workers performing specific tasks at a GDF for the illustrative conceptual designs for the three selected geologies. Doses specific to tasks and locations within the GDF are then reported and commented upon with respect to the Radiological Protection Policy Manual.

Dose assessments for specific operators who may perform a number of tasks will appear in future issues of this report once a work schedule is available.

This report also covers illustrative shine doses from packages, located at the surface facilities in transport containers before being moved underground, that might affect members of the public. Illustrative doses to the public from routine operational gaseous discharges are covered in the Generic Operational Environmental Safety Assessment (OESA) and are not within the scope of this report. It should be noted that external radiation hazards dominate worker example routine doses but inhalation/ingestion doses dominate public example doses from routine operations reported in the OESA.

Illustrative doses are presented for routine operations within a GDF for various geologies. The higher strength rock illustrative concept design is taken to be the base case. Where operations differ in the two other illustrative geologies, separate doses are determined and presented.

Illustrative doses to workers in areas that may contain contamination but do not contain waste packages (such as the ventilation and support halls) are not considered in this report at this time, however they will be addressed in future issues of this report. This is also the case for areas which use remote operations and have limited man access, for example the high level waste (HLW) transfer hall in the higher strength rock geology. The contribution to annual illustrative dose from these areas is anticipated to be significantly smaller in comparison to the illustrative dose from those containing waste packages but will be assessed in the future. Illustrative doses to workers due to airborne contamination both on the surface and underground are discussed. However the contribution to inhalation illustrative dose due to natural radon is site specific and will be addressed in future issues of this report when site characterisation data are available. It is expected that the HSE
guidance on Radon in the workplace [11] and the 400Bq m$^{-3}$ action level for application of the Ionising Radiations Regulations 1999 (IRR1999) [12] will be adhered to.

Radiological and non radiological accidents are covered by other volumes of the OSC (volumes 3 and 1 respectively), therefore accidents are not discussed in this volume. An accident is any unintended event, including operator errors, equipment failures or other mishaps, the consequences or potential consequences of which are not negligible from the point of view of protection of safety. This is also the case for criticality accidents (volume 4). Routine doses to the public from gaseous or liquid effluent discharges are covered in the OESC and for this reason are also excluded from this report.
2 GDF description

2.1 Waste inventories

The generic DSSC considers disposal of the following categories of radioactive wastes:

- Intermediate level waste (ILW) and some low level waste (LLW) not suitable for consignment to the Low Level Waste Repository (LLWR);
- High level waste (HLW);
- Spent fuel (SF), plutonium and uranium (HEU and DNLEU) stocks which may be designated as wastes in the future.

The NDA, in conjunction with Department of Environment, Food and Rural Affairs (Defra), maintains the UK Radioactive Waste Inventory (UK RWI) – a compilation of UK radioactive waste holdings [13]. The MRWS White Paper [1] used information from the 2007 UK RWI to produce a ‘Baseline Inventory’ of the radioactive materials that may be required to be disposed of to a GDF.

However, the Baseline Inventory does not contain sufficient detail to provide a basis for the concepts and assessments supporting the DSSC. A series of derived inventories have therefore been developed for each of the materials included in the Baseline Inventory. These have been assembled into a reference Case Derived Inventory which is described in the Disposal System Technical Specification (DSTS) [14]. The UK RWI and hence, the derived inventories are compiled from projections made by waste producing organisations, on the basis of their current assumptions regarding the nature, scale and timing of future operations and activities that would result in the generation of radioactive waste. The Reference Case Derived Inventory is summarised in Table 1. For further breakdown of the inventory including further details on the quantities and characteristics of the wastes the DSTS itself should be consulted, alternatively summary information is provided in supporting report Radioactive wastes and assessment of the disposability of waste packages [15].

<table>
<thead>
<tr>
<th>Materials</th>
<th>Activity at 2040 (TBq)</th>
<th>Packaged Volume (m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HLW</td>
<td>$1.7 \times 10^7$</td>
<td>7,457</td>
</tr>
<tr>
<td>ILW</td>
<td>$1.6 \times 10^6$</td>
<td>361,692</td>
</tr>
<tr>
<td>SILW</td>
<td>$1.5 \times 10^3$</td>
<td></td>
</tr>
<tr>
<td>LLW</td>
<td>$8.2 \times 10^2$</td>
<td>16,632</td>
</tr>
<tr>
<td>SF</td>
<td>$3.8 \times 10^7$</td>
<td>10,363</td>
</tr>
<tr>
<td>Plutonium</td>
<td>$3.8 \times 10^5$</td>
<td>6,989</td>
</tr>
<tr>
<td>Uranium (DNLEU &amp; HEU)</td>
<td>$5.0 \times 10^3$</td>
<td>94,502</td>
</tr>
</tbody>
</table>

In order to consider the range of credible variations in future waste arisings an Upper Inventory has also been developed. The Upper Inventory considers changes to the Reference Case that could be assigned through alternative power generation and reprocessing scenarios, including the introduction of additional wastes from the operation and decommissioning of new nuclear power stations in the UK.

The Upper Inventory is described in the DSTS and its impact on geological disposal has been considered in a qualitative fashion by all components of the DSSC. The Upper
Inventory results in an increased volume of all types of waste and therefore the period of operation of a GDF would be extended. Regulatory limits and targets are set on an annual basis so an extended period of operation has no significant effect on the acceptability of our safety assessment. The NDA specifications for intermediate level waste packages [16] recommend that packages be designed to maintain their integrity for a target period of 500 years. Hence extending the period of operation of a GDF to allow for disposal of a larger inventory would not affect the analysis appreciably.

2.2 Waste packages

2.2.1 ILW/LLW waste packages

Standards and specifications have been developed for the packaging of ILW/LLW wastes, in order to provide assurance that waste packages currently being manufactured, will be compatible with the safe operation of a GDF. Packaging requirements are detailed in the Generic Waste Package Specification (GWPS) and supporting documents [16].

In conjunction with the waste producers, the NDA have so far specified the following waste containers (see Figure 1) for packaging the vast majority of ILW and LLW being put forward for disposal within a GDF:

- 500 litre drum
- 3 cubic metre box (3m³ box)
- 3 cubic metre drum (3m³ drum)
- 4 metre box (4m box)
- 2 metre box (2m box).
The 500 litre drums, 3m³ boxes and 3m³ drums are unshielded containers that are used as waste packages but will need to be loaded within a reusable transport container for shipment to a GDF. Once removed from the transport container at a GDF, these waste packages will need to be handled by remote means. A conceptual design has been developed for a Standard Waste Transport Container (SWTC). This assessment considers SWTCs with either 285mm or 70mm of steel shielding. Each SWTC will hold either one 3m³ box or 3m³ drum or four 500 litre drums in a stillage. The combination of SWTC and
waste package(s) will meet the requirements for a Type B(U) transport package as defined by the IAEA Transport Regulations [17].

Some wastes may be packaged in stainless steel 2m or 4m boxes, which may be concrete lined, providing integral shielding. These packages are designed to be transported and handled without any additional shielding or containment. They are designed to be compliant with the IAEA definition and performance requirements for an Industrial Package Type 2 (IP2). In line with the IAEA Transport Regulations, the allowable contents of these packages are limited to wastes that qualify as Low Specific Activity (LSA) materials and/or Surface Contaminated Objects (SCO). These shielded packages will be placed directly in the disposal facility.

For most waste packages, the raw radioactive waste will be immobilised to form a disposable wasteform within the waste container – with the combination of wasteform and waste container forming the waste package. A description of the approach to definition of safety functions within waste packages, including contribution from the wasteform and waste container is given in the Radioactive wastes and assessment of the disposability of waste packages [15]. To date, many packages incorporate a cementitious wasteform although other approaches, such as use of polymer binders, or provision of robust containers may also be used.

2.2.2 HLW/SF packages

Depending on the chosen geology in each of the illustrative example concepts, it is assumed that HLW and SF would be packaged in a robust disposal canister manufactured either in copper with cast iron internals (hard rock disposal concept) or in steel of similar dimensions and robustness for the other two geological settings. Final decisions on the design of canister and construction materials have not yet been made as this will depend upon the host geological environment and detailed GDF design adopted. HLW comprises high active liquors immobilised as a vitrified glass form in 150 litre steel containers. It is assumed that PWR and Advanced Gas-cooled Reactor (AGR) spent fuel assemblies would be loaded and sealed inside the disposal canister with minimal pre-treatment. PWR assemblies would be packaged as complete fuel assemblies while AGR fuel elements would be disassembled and fuel pins consolidated into bundles in a stainless steel basket.

Current proposals are that all disposal canisters would be 0.9-1.0 metre diameter. The HLW canisters would be around 3.2 metres in length and capable of holding two HLW containers. The SF canisters are likely to vary in length from 2.5 metres to 5 metres approximately, depending on the design of the fuel assemblies to be packaged.

Because of their high inventories, it is anticipated these packages would be transported and handled in heavily shielded flasks (termed disposal canister transport containers or DCTCs), which would comply with the requirements for a Type B package under IAEA regulations [17].

2.2.3 Pu/HEU packages

At this stage it has been assumed that plutonium and high enriched uranium (HEU), if declared as waste, would be packaged in a similar design of disposal canister to that proposed for HLW/SF and would also be transported to a GDF in a DCTC. The exact nature of the packaging process has yet to be determined but, in order to enable safety assessments to be conducted for the DSSC, it is assumed that Pu/HEU would be converted into titanium-based ceramic pucks, with multiple pucks being placed in a stainless steel can. Multiple cans of pucks would then be encapsulated in glass in a large canister which would, in turn, be placed in the disposal canister.
2.2.4 DNLEU packages

It is assumed that depleted, natural and low enriched uranium (DNLEU) would be packaged in the form of uranium oxide in 500 litre drums. The drums would be transported in SWTCs and would be emplaced in the disposal vaults for unshielded packages.

2.3 Disposal concepts

For the generic DSSC, illustrative geological disposal concept examples have been developed to examine the safety aspects of a GDF with respect to normal operations and potential accidents.

Six illustrative concept examples have been developed - one for each different host rock type and package type (i.e. ILW/LLW or HLW/Pu/SF). These are based on geological disposal concepts that have previously been developed in the UK or are being developed under national programmes in other countries. The three concept examples chosen are listed in Table 2 below, together with the published concepts on which they are based.

Table 2 Illustrative geological disposal concept examples

<table>
<thead>
<tr>
<th>Host rock</th>
<th>Illustrative geological disposal concept examples (developer, country)</th>
<th>ILW/LLW/ILWLEU</th>
<th>HLW/SF/Pu/HEU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher strength rocks(^{1}) (igneous/metamorphic/sedimentary)</td>
<td>UK ILW/LLW Concept (NDA UK)</td>
<td>KBS-3V Concept (SKB, Sweden)</td>
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</tr>
<tr>
<td>Lower strength sedimentary rock(^{2})</td>
<td>Opalinus Clay Concept (Nagra, Switzerland)</td>
<td>Opalinus Clay Concept (Nagra, Switzerland)</td>
<td></td>
</tr>
<tr>
<td>Evaporites(^{3})</td>
<td>WIPP Bedded Salt Concept (US DOE, United States)</td>
<td>Gorleben Salt Dome Concept (DBE Germany)</td>
<td></td>
</tr>
</tbody>
</table>

Notes:

1. Higher-strength rocks – the UK ILW/LLW concept and SKB’s KBS-3V disposal concept were selected because of the availability of information on these concepts for the UK context. Supercontainer options (such as the KBS-3H concept) would also need to be considered in our future work, if a candidate community comes forward in an area of the UK providing access to suitable higher-strength rock at GDF depth.

2. Lower-strength sedimentary host rocks – Nagra’s concepts for Opalinus Clay were selected because a recent NEA review regarded the Nagra work as state of the art [18]. However, it should be noted that there is similarly extensive information available for the French (Andra) concepts (for Callovo-Oxfordian Clay), which have also been accorded strong endorsement from international peer review. Although the Swiss concepts are used as the basis of the illustrative geological disposal concept examples in the Generic ESC, as we move forward we would also draw on information from the French programme and from the Belgian HLW/SF supercontainer concept, if a candidate community comes forward in an area of the UK providing access to suitable lower-strength sedimentary rock at GDF depth.

3. Evaporites – the concept developed by the US DOE for transuranic wastes at the WIPP was selected because of the wealth of information available from a licensed facility that has been operating for more than 10 years, and the concept developed by the German Company for the Construction and Operation of Waste Repositories (DBE) for HLW/SF was selected because of the level of information available for it.

Illustrative geological disposal concept examples have been developed for each of these geologies for the DSSC. These are described in turn below. It should be noted that many of the assumptions in these examples (such as the depth of the underground facilities) are derived from the published concepts. While they are typical for the geologies, the actual
parameters developed for a site-specific design would be dependent on the characteristics of the chosen site.

2.3.1 Higher strength host rock

The illustrative concept example for the higher strength rock is described in [8]. It is envisaged that this would be a stand-alone development on a single surface site. It is assumed that the underground facilities would be developed on a single horizon at 650 metres below ground level. The concept would comprise a number of basic elements including:

- Surface Facilities
- Underground Access
- ILW/LLW Disposal Area
- HLW/SF Disposal Area.

Surface facilities

It is assumed the surface facilities would be divided into two separate groups: those serving construction activities (on the ‘shafts area’ of the site) and those serving package emplacement activities (on the ‘drift area’ of the site). As there will be a need for continuing construction work after the commencement of emplacement operations, the aim would be to separate construction and emplacement activities as far as possible with separate access and ventilation arrangements.

A typical surface layout is shown is Drawing 1 (Appendix A)

The shafts area facilities would be the first to be developed and would be used to service underground development of a GDF. Once the GDF was operational, the shafts area would continue to be used to provide underground access for all construction personnel and materials and the export route for excavated rock.

The main function of the drift area facilities would be the receipt and handling of in-coming waste packages and their transfer to the drift train for transfer to the underground emplacement facilities through the drift tunnel.

Waste packages would be delivered to the GDF by road or rail and would be held at the Gate Receipt Area while security and documentation checks were carried out. Rail sidings and HGV parking would be provided on-site to accommodate rail wagons and lorry trailers, holding packages awaiting transfer underground.

The main surface facilities for waste package and transport container handling would comprise the Waste Package Transfer Facility (WPTF) and the Transport Container Maintenance Facility (TCMF).

At the WPTF, the waste packages would be transferred from the delivery unit to the drift wagon for transportation underground. All unshielded ILW/LLW packages and all disposal canisters would be transferred underground in their transport containers. The TCMF would contain facilities for the decontamination, inspection and maintenance of empty transport containers. It would also have remote handling facilities for inspection and rectification of any incoming transport containers failing acceptance tests. This would, therefore, be the only surface facility where the lid might be removed from a transport container containing an unshielded package.

Additional active facilities providing support to the main operational plants would include liquid effluent treatment and active ventilation plants, an active laundry and laboratories. There would also be facilities for the maintenance of the drift train and the shunting locomotive which would be used to transfer the mainline rail wagons onto site.
Underground access

In this concept example, it is assumed that underground access would be provided by an inclined tunnel (termed the drift) and shafts. The drift would be used for the transfer of waste packages underground and would be equipped with a rack-and-pinion single track rail system. Underground emplacement operators would also travel via the drift, but separately from the waste packages. Access for construction workers and equipment would be by vertical access shaft. A separate shaft would be provided for the export of excavated rock. These two shafts would provide the ventilation intake and return respectively for the construction area. Ventilation to the emplacement areas would be provided by the drift with a third shaft being provided for the ventilation return.

ILW/LLW disposal area

Unshielded packages would be transferred down the drift in SWTCs. At the bottom of the drift, there would be a receipt and marshalling area, where the SWTCs would be transferred to a shielded cell line. Here the unshielded package unit would be removed from the SWTC and monitored before being transferred to the disposal vaults.

In the current concept example, it is assumed that each disposal vault for unshielded packages would be 16 metres wide by 16 metres high and 300 metres long. A remotely operated crane would be used to place the packages in the disposal vault where they would be stacked in arrays (e.g. 7 high x 7 wide, for 500 litre drum stillages). DNLEU packages would also use this route.

The shielded waste packages have low surface dose rates and do not require remote handling. It is currently assumed they would be emplaced in separate disposal vaults of similar dimensions to those for unshielded packages. Shielded packages would be accumulated in a buffer store located near the entrance to the disposal vault and transferred to the vault in campaigns using a large capacity, manually driven, stacker truck. They would be stacked in arrays (e.g. 5 high x 3 wide, for 4 metre boxes).

For the Derived Inventory Reference Case, this concept assumes that 19 vaults would be required for unshielded packages and 6 vaults for shielded packages.

HLW/SF disposal area

In the illustrative concept example for higher strength rock, it is assumed the HLW/SF disposal area would consist of disposal tunnels designed for in-floor emplacement of individual disposal canisters within vertical deposition holes.

Each HLW/SF disposal canister would be taken underground in its DCTC and transferred by overhead crane from the drift wagon to the Transfer Hall. The disposal canister would be removed from the transport container and transferred to a shielded tube within the deposition machine. The deposition machine would then transport the disposal container to a disposal tunnel and then to a deposition hole prepared with bentonite blocks and rings. The mobile part of the shielding would be lowered to the tunnel floor and the shield tube would be tilted to the vertical and lowered down into the deposition hole. Each deposition hole would have a chamfer on the leading edge to permit the canister to be rotated while it is being emplaced. The disposal canister would then be lowered into the disposal hole and bentonite blocks installed above the disposal canister using the deposition machine.

Nominal disposal tunnel dimensions of 5.5 metres high by 5.5 metres wide with a ‘D’ shaped excavation profile have been assumed in the concept example. Each disposal tunnel would be nominally 340 metres long and it is envisaged that each disposal tunnel would accommodate 44-48 deposition holes.

Pu/HEU disposal canisters would also be emplaced using this route.
For the Derived Inventory Reference Case it has been assumed that 296 disposal tunnels would be required.

A schematic underground layout for this concept example is presented in Drawing 2 (Appendix A).

**Backfilling and closure**

In this concept example, the HLW/SF disposal tunnels would be back-filled when all deposition holes in a tunnel had been filled. This option is judged to be the most effective option for hazard reduction to workers in particular. A mixture of crushed rock and bentonite would be used for the backfill. The purpose of the backfill is to provide another barrier, protecting the biosphere from radioactive contamination by restricting diffusion of radionuclides.

In the case of ILW/LLW/DNLEU disposal vaults, provision has been made for the disposal vaults to be back-filled in one stage once all the wastes have been emplaced. This aligns with an enhanced retrievability option. The backfill would comprise two elements, namely:

- Local backfill, to fill the space around and in the immediate vicinity of the packages;
- Peripheral backfill, to fill the void between the stacks of waste packages and the walls of the vaults.

The backfill material would be a cementitious grout – possibly the Nirex Reference Vault Backfill (NRVB). We currently assume that backfilling would take place in a single campaign, using backfill galleries sited above the vaults. The main access ways and underground roadway structure would then be backfilled and sealed.

**2.3.2 Lower strength sedimentary host rock**

For lower strength sedimentary host rocks, the Swiss concept developed by NAGRA for Opalinus Clay, has been selected as the basis for the illustrative geological disposal concept example for both ILW/LLW and HLW/SF.

**Surface facilities and underground receipt**

The concept example for lower strength sedimentary host rock is described in [8]. It is assumed that the surface facilities, underground access and the ILW/LLW receipt and marshalling area would be very similar to the higher strength rock concept. The overall height of the receipt and marshalling area would be lower in some parts but apart from these lower lift heights, package-handling arrangements would be essentially unchanged.

The main difference is that, due to the reduced durability of the lower strength sedimentary rock, a shorter operational life has been assumed for the inlet cell and vault structures. The concept example therefore provides for a separate inlet cell for each disposal module for un shielded packages.

The lower strength sedimentary rock concept example would not utilise a deposition machine for HLW/SF disposal. Rather, the disposal canisters would be transferred to the disposal tunnels in their DCTCs: this process is described in the next section.

**Emplacement and backfilling**

The dimensions of the disposal vaults would be smaller than those for the higher strength rock example concept. Thus, for un shielded packages, the number of disposal vaults required for the Derived Inventory Reference Case would be 169, compared to 19 for the higher strength rock. The current lower strength sedimentary rock concept example assumes an arrangement of up to 5 modules each comprising 40 vaults in groups of 8. The actual layout would obviously depend on the characteristics of the chosen site.
Given the reduced vault heights, it has been further assumed that unshielded packages would be stacked in smaller arrays (e.g. 3 package units wide and 5 package units high for 500 litre drum stillages).

In the lower strength sedimentary rock concept example, there would be no requirement to lift unshielded packages into the disposal vaults. Rather, they would be transferred horizontally through an interlocking system of shield doors. The packages would again be placed in position by overhead crane.

For shielded packages, the number of disposal vaults required for the Derived Inventory Reference Case would be 77 compared to 6 for the higher strength rock concept example. 4m boxes would be stacked in single rows, 3 high compared to the 5 high stacks envisaged for the higher strength rock. Thus, the lifting heights required would again be reduced. A manually driven stacker truck would again be used for emplacement but, due to the single rows, less manoeuvring space would be required.

Due to the reduced stability of the rock structure, compared to higher strength rock, each disposal module would be backfilled immediately after it had been filled. During the backfill process the shield doors at the entrance to each disposal vault for unshielded packages would act as a containment wall to aid the process. The disposal vaults for shielded packages would require the construction of a containment wall before they could be backfilled.

HLW/SF disposal canisters would be emplaced in disposal tunnels similar to those envisaged for the higher strength rock concept example. However, the canisters would be placed end to end horizontally in the tunnels rather than in individual deposition holes. Each disposal tunnel would be of the order of 800 metres long and the entrance to each tunnel would be fitted with a double set of shield doors. The disposal canister would be transferred to the tunnel entrance in its DCTC. The disposal canister would then be transferred by remote means to a disposal trolley that had been preloaded with bentonite blocks which would support the disposal container from below when it is emplaced in the disposal tunnel. Canister and blocks would be lowered as a unit to the floor of the disposal tunnel and released from the trolley.

The volume of the disposal tunnel around the disposal canister would be filled with bentonite pellets, immediately after placement of the canister. The bentonite pellets would be put in place by employing a mobile hopper. The mobile hopper would be moved to the far end of the deposition tunnel, over the disposal canister that had just been emplaced. Bentonite pellets would be discharged to fill the area beyond the disposal canister and the hopper would then be gradually withdrawn to fill the area all around the disposal canister. The mobile hopper would then be withdrawn from the tunnel.

For the Derived Inventory Reference Case, the lower strength sedimentary rock concept example assumes that 99 disposal tunnels would be required.

An example layout is depicted schematically in Drawing 3 (Appendix A)

2.3.3 Evaporite host rock

For evaporites, the US concept for radioactive transuranic wastes (TRU) at the Waste Isolation Pilot Plant (WIPP) has been used as the basis for the illustrative geological disposal concept example for UK ILW/LLW, together with the German concept for HLW/SF under development at Gorleben, as the basis of the concept example for UK HLW/SF. Details of our illustrative concept example, adapted for UK conditions, are given in [8]. For this concept example, a bedded halite (rock salt) has been chosen; that is, the host rock is assumed to comprise a bed of salt deposit overlain by permeable sedimentary rock. It has been further assumed that the host rock is sufficiently extensive vertically and horizontally to accommodate a GDF.
Surface facilities and transfer underground

The evaporites concept example, as it is currently envisaged, would not include drift access. Rather, a fourth shaft would be provided for the transfer underground of waste packages and emplacement operations personnel. HLW/SF disposal canisters in DCTCs, unshielded packages in SWTCs and shielded packages will all be transferred underground in this way. It is noted that this is a facet of the Gorleben design on which the concept example is based. Evaporite rocks exhibit ‘creep’ whereby the excavation boundary slowly moves and the roof and side walls ‘flow’ into the excavation. Rock bolts and mesh would be provided as a primary support where required but the excavation dimensions would gradually decrease. Hence, although the use of a drift within this geology would be technically feasible, it would have significantly higher maintenance requirements compared to the other geologies.

Receipt underground & transport to emplacement area

The operations here would be similar to those for the lower strength sedimentary rock concept example. While most excavations would be no more than 5.5 metres high, an inlet cell of similar dimensions to that for the lower strength sedimentary rock would be provided for the removal of unshielded packages from their SWTCs.

The creep properties of the evaporite rocks would limit the operational time available. Therefore, in order to avoid repeated excavation activities in the vicinity of the primary remote handling facilities a similar strategy would be proposed to that adopted for the lower strength sedimentary rock, namely the provision of a separate inlet cell for each disposal module for unshielded packages, constructed at the same time as the disposal module.

As for the lower strength sedimentary rock, the HLW/SF disposal canisters would be transferred to the disposal tunnels in the DCTCs.

Emplacement and backfilling

The dimensions of the disposal vaults for unshielded and shielded packages would be similar to those for the lower strength sedimentary rock concept, with 167 disposal vaults for unshielded packages and 38 disposal vaults for shielded packages being required for the Derived Inventory Reference Case. In the concept example, the stack and workface dimensions for the disposal vaults would also be the same as for the lower strength sedimentary rock. The actual layouts and dimensions in a site-specific design would depend on the site characteristics. An idealised layout is shown in Drawing 4 (Appendix A).

Due to the characteristics of the geology, unshielded packages would be emplaced using a remotely-operated stacker truck in order to avoid the use of an overhead crane. Guide rails could be used to improve emplacement precision. As for the lower strength sedimentary rock, the transfer tunnel and the vaults would be on the same level, allowing the packages to be transferred horizontally, through shield doors, from the transfer tunnel bogie to the stacker truck.

No backfilling of the disposal vaults would be proposed. Rather, the strata would be allowed to creep to fill in the voids. Sacks of magnesium oxide would be placed on top of each stack of packages to remove moisture.

The emplacement of HLW/SF disposal canisters in disposal tunnels would be similar to that described for the lower strength sedimentary rock concept example, except that the canisters would be moved into the disposal tunnels, slung under an emplacement frame and placed directly on the tunnel floor. The disposal canister would be transferred by remote means to the emplacement frame and lowered close to the floor for transportation to its emplacement position where it would be lowered the remaining distance to the floor and detached from the emplacement frame which returns to the tunnel entrance for re-use.
The volume of the deposition tunnel around the disposal canister would be filled with crushed rock salt, (excavated during the construction activities) immediately after placement of the disposal canister.

The crushed rock salt would be put in place by employing a mobile hopper. The mobile hopper would be moved to the far end of the deposal tunnel, over the disposal canister that had just been emplaced. The crushed rock salt would be discharged to fill the area beyond the disposal canister and the hopper would then be gradually withdrawn to fill the area all around the disposal canister. The mobile hopper would then be withdrawn from the tunnel.

2.3.4 Retrievability

In line with EA guidance [19], the GDF is intended as a disposal facility, rather than a storage facility. This means that it will be designed in such a way that the waste can safely remain in the facility and not require subsequent retrieval. Nevertheless, the DSFS recognises the requirement of the MRWS White paper [1] not to foreclose the option of retrievability and specifies that the design and construction of a GDF should, where possible, be carried out in such a way as not to preclude the option of extended retrievability. This may mean that, for a period of time after the waste emplacement phase, monitoring of the emplaced wastes would be required until the decision is taken to backfill, seal and close. During this time, it would be possible to retrieve the waste for disposal elsewhere.

The extent to which retrievability is feasible depends on a range of factors, including the nature of the geological environment in which a GDF is sited. Future decision-making regarding retrievability will need to take account of relevant site-specific characteristics.

In some concepts the waste packages can indeed be emplaced in such a way that they can be retrieved relatively easily at any time until the facility is sealed and closed. This is the case for ILW/LLW waste packages in the illustrative concept example for higher strength rock. The concept currently provides the option for delayed backfilling of the vaults until just prior to closure. This means that the waste packages could be retrieved by a simple reversal of the emplacement process. Assuming no deterioration of package integrity and ability to maintain vaults and handling systems operable, the safeguards in place to protect against fault conditions during emplacement would also protect against faults occurring during retrieval.

Retrieval of disposal canisters from the HLW/SF/Pu/HEU disposal areas would be more difficult, since the current concept anticipates that the deposition holes will be backfilled with bentonite and the disposal tunnels backfilled with rock, immediately after all the holes in a single disposal tunnel have been loaded with waste.

The same approach to backfilling of the HLW/SF/Pu/HEU disposal areas is adopted in our other concepts, except that the backfill materials used are bentonite pellets and crushed salt for the lower strength sedimentary rock and evaporite concept examples respectively. The buffer material is designed to protect the disposal canisters and prevent or reduce groundwater flow around them. Subsequently, should the canister lose its integrity in the post-closure phase, the buffer also helps to slow down the release the radionuclides.

For the lower strength sedimentary rock and evaporites concept examples, the characteristics of the geologies mean that it is technically more difficult to keep the disposal vaults open for extended periods. Currently, for these concepts, an operational life of 15 years is assumed for each disposal module and associated inlet cell, after which time that module would be backfilled. Extending the operational life of the vaults beyond that time would require extensive maintenance or replacement of the structural supports. In the evaporites concept example, depending on the creep rates, maintaining access to the packages could require repeated re-excavation to off-set the natural in-filling of evaporite. This would be costly and could also be technically challenging, particularly given the need...
to maintain safe working conditions and limit operational doses in the vicinity of the vaults containing unshielded packages.

However, various studies have been undertaken internationally to demonstrate retrievability of waste packages. In particular, Nirex have demonstrated the feasibility of using high-pressure water jets to retrieve ILW packages from disposal tunnels backfilled with NRVB [20]. More recently, SKB (the Swedish Nuclear Fuel and Waste Management Company) has demonstrated that waste canisters can be retrieved from a saturated bentonite buffer by slurring it with a saline solution [21].

The potential for cavern failure (due e.g. to rock falls or groundwater ingress) is likely to increase as the timescales over which the facility needs to remain open increase. Backfilling each section immediately following emplacement reduces this risk and provides physical protection for the waste packages. It also avoids the potential risks to workers associated with extensive monitoring and maintenance of the structures. This is in addition to the obvious benefits of early closure, recognised in [1], of greater safety, greater security against terrorist attack and a reduction in the worker dose burden transferred to future generations.

If provision is to be made for possible retrieval of the waste packages at some point in the future then it may be necessary to monitor the condition of the packages. A key technical issue here, therefore, is the need to better understand package longevity and the corresponding degradation mechanisms over a long period of storage. As part of the work underpinning the DSSC, further research into package longevity has been commissioned [22]. The aim of the work is to investigate whether it may be better to remove reliance on continuing package integrity by backfilling before degradation mechanisms have had time to adversely affect package performance.

Improved understanding of such issues will allow an informed assessment of the balance of the benefits of not foreclosing on potential disposal options against the potential risks associated with the need to provide for retrievability. The implementation programme for MRWS is such as to allow for decisions regarding the optimal closure strategy to be decided at a later date when further research and assessment has been undertaken.

2.4 Basis for assessment

The generic OSC is required to support the Letter of Compliance disposability assessment process. This is the process whereby NDA RWMD advises waste producers on the disposability of packaged wastes during the development of conditioning and packaging processes before the waste packages are manufactured.

Through this process we use our generic designs and safety cases to check that the waste packages will be transportable and disposable. This process is important for the DSSC and OSC in particular as it gives confidence that the safety case is taking due account of waste packages and is compatible with real waste packages as being developed by industry. The process is very important for waste producers too as it gives confidence that investment in plant to recover and package waste will result in waste packages which can be transported and disposed to a future GDF.

Prior to the production of the generic DSSC the LoC process was based on concept geological disposal designs for ILW (the Phased Geological Disposal Concept (PGRC)) [23] and for HLW/SF [24]. The LoC process requires quantified safety assessments in order to fully understand the issues associated with specific wastes and waste packaging proposals. To this end both the ILW and HLW/SF concept designs were supported by operational safety assessments [25,26].

To facilitate continued support for the LoC disposability assessment process it is necessary for the generic OSC to be sufficiently quantified to continue to serve the purpose outlined above. To this end the scope of the OSC includes a quantified example assessment based
on the illustrative concept examples. To maintain a consistent thread with previous work the example assessment is based on the two illustrative concept examples for the higher strength rock geological environment.

The two illustrative concept examples for higher strength rock are considered to provide a good representative basis for quantified assessments because they include all receipt, handling, transfer and emplacement activities, and in the most-part present worst-case scenarios (cavern drop heights for instance). There are two exceptions to this:

(i) the concept example for evaporite which proposes the use of a shaft in preference to a drift for transferring waste packages underground. Clearly the use of a shaft introduces a completely new set of potentially very serious impact faults, including cage falls and ‘cage absent’ accidents. Justification of this aspect would require detailed design basis accident analysis and, possibly, severe accident analysis to be undertaken in the future.

(ii) the concept examples for lower strength sedimentary rock and evaporite, introduce the use of additional shield doors (e.g. at the entrances to the ILW vaults and the HLW/SF disposal tunnels). This will increase the potential for external exposure faults resulting from failure of access controls.
3 Methodology

3.1 Introduction to the methodology used in this report

In 2003 the Generic Operational Safety Assessment Part 5 (GOSA) [25] presented a scoping assessment of potential radiation doses to workers from the routine operation of a generic geological disposal facility (GDF). This document did not consider how radiation doses might be affected by the geology in which the facility was constructed. The GOSA is one of the sources of information used to identify the possible exposure pathways within this report. Information regarding the layout of a GDF created in the different geologies is provided in the supporting report Generic disposal facility designs [8].

Where it was deemed appropriate, illustrative doses have been calculated using the same methodology as employed in the GOSA. However, this report builds on the methodology used in the GOSA as parameters have been updated to align with current thinking. The following inclusions and modifications to the GOSA methodology have been made:

- **Different geologies:** A GDF concept may involve construction in one of three main example types of geology (assumed in the UK). These include:
  - higher strength rock [8]
  - lower strength sedimentary rock. In this concept, dimensions of caverns and disposal areas are assumed to be smaller in size than those for the higher strength rock [8]. This will have an impact on the size of the arrays of the waste packages in these areas
  - evaporite. In this geology, the main effect is possible creep of the geology, this changes timing and other operational aspects over the life of the facility [8]

- **Inclusion of other forms of radioactive waste:**
  - high level waste (HLW) in the form of vitrified product overpacked in a robust disposal canister
  - spent fuel (SF) in the form of spent fuel assemblies overpacked in a robust disposal canister
  - plutonium (Pu) in the form of a ceramic waste form in a robust disposal canister
  - uranium in the form of an oxide in 500 litre drums

In this report illustrative doses and dose rates are discussed only for areas and operations where there are both operators and waste packages present. Areas where handling is carried out remotely from outside the area, or where any dose would be due to contamination rather than physical sources are left for future issues of this report.

It is anticipated that annual illustrative doses from surface operations would be independent of the geology of a GDF; therefore this report separates surface and subsurface activities.

3.2 Methodology for surface facilities activities

The surface facilities provide all the necessary support for ongoing construction and the provision of essential services (power, water and ventilation). Management and administration buildings are also located on the surface.

The surface facilities also include those for the receipt and transfer of waste from rail or road transport to the underground disposal vaults and tunnels. The surface facilities are mainly independent of vault geology, the main difference being the use of an inclined drift...
tunnel system for the higher strength rock and lower strength sedimentary rock. In these geologies the packages are transported underground via the drift transport system – a rack and pinion rail system. In addition there would be three shafts. Two of the shafts would be used for construction and the development of the underground infrastructure. The drift and a third shaft would provide the emplacement intake and return ventilation system. For the evaporate facility there would be no drift and four shafts would provide access to the underground facilities and workings [8].

A number of activities have been previously identified in the reference documents [2, 8,25,27]. By matching operational activities [2,25,27] to locations [8] and hence the waste package type and quantity, illustrative dose rates for each surface facility operation are calculated.

Locations in which operations are calculated are:

- **Surface:**
  - Gate receipt area
  - Rail Sidings
  - Trailer Park
  - General (airborne activity)
  - Waste Receipt building (for inclusion in future issues).

- **Underground:**
  - Drift
  - Shielded intermediate level waste (SILW) / low level waste (LLW) vault
  - Buffer Store (for inclusion in later issues)
  - HLW/SF/Pu disposal tunnel
  - Inlet cell
  - General (airborne activity).

As has been previously stated in Section 1.3.1, other general areas which do not contain waste packages will be included in future issues of this report. This will also include the doses associated with effluent management including that due to the presence of effluent bowsers as well as the dose incurred during maintenance activities.

To assess the illustrative dose to operators working in other surface facilities, scoping calculations based upon realistic source terms and assumed operational scenarios have been performed. The Fault and Hazard Schedule [25] presents a description of the derivation of Bounding Hazards. The ‘Bounding Hazards’ are effectively dose rates at a set distance from packages. The exceptions to this definition are the bounding hazards for airborne activity concentration, which were derived differently. The surface airborne contamination Bounding Hazard represents the dose rate at 100m from the ventilation point. No reduction for the removal of particulates by the HEPA filtration has been accounted for. Radon daughters are assumed to be in equilibrium with Rn-222. This Bounding Hazard has been updated since 2003 to incorporate improved radionuclide data [28]. In keeping with the methodology of this report, illustrative dose rates in specific areas are based on the waste types present in the area. Bounding Hazards were initially stated in the 2003 GOSA [25]. Dose rates from packages containing HLW/spent fuel (SF)/Pu were not assessed in the 2003 GOSA but are included in this report, based on the assumption that dose rates from these packages will not exceed the assigned transport limit of 0.1 millisievert/hour (mSv/h) at 1 m. This would be consistent with the maximum dose rate at 1 m from a type II yellow category package in accordance with the IAEA Regs. [17].
These ‘Bounding Hazards’ are multiplied by a scaling factor, the ‘Bounding Hazard factor’, employed in order to make the calculation more representative of the particular scenario and exposure time. Thus, a representative but bounding consequence assessment has been performed for each hazard.

Annual illustrative doses to all other operators in surface facilities were calculated based on the ‘Bounding Hazards’ methodology. Table 3 shows the values of Bounding Hazards used in this report for surface workers. Dose rates from HLW have been included. These were found to be bounding with regards to HLW/SF or Pu. Note that in Table 3 the suffix T refers to packages transported by road.

Table 3  Dose rates for Bounding Hazards, normal surface operations, updated with current thinking

<table>
<thead>
<tr>
<th>Bounding Hazard</th>
<th>Hazard description</th>
<th>Estimated dose rate to operator (mSv/hr) reference case, including HLW/SF/Pu</th>
</tr>
</thead>
<tbody>
<tr>
<td>BH N1</td>
<td>External dose rate to worker, 1 m from a package in its transport configuration.</td>
<td>$1.00 \times 10^{-1}$</td>
</tr>
<tr>
<td>BH N1T</td>
<td>External dose rate to worker in the Surface Trailer Park 1 m from a package in its transport configuration.</td>
<td>$1.00 \times 10^{-1}$</td>
</tr>
<tr>
<td>BH N2</td>
<td>External dose rate to worker 10 m from a package, in its transport configuration.</td>
<td>$5.05 \times 10^{-3}$</td>
</tr>
<tr>
<td>BH N2T</td>
<td>External dose rate to worker in the Surface Trailer Park 10 m from a package in its transport configuration.</td>
<td>$5.05 \times 10^{-3}$</td>
</tr>
<tr>
<td>BH N4</td>
<td>Worker dose rate for airborne contamination at the surface, from routine operations</td>
<td>$7.62 \times 10^{-8}$</td>
</tr>
<tr>
<td>BH N8</td>
<td>External dose to worker close to an open, empty reusable transport container for a short duration - not evaluated. The assumption is that normal operations would not allow operators near open and empty reusable transport containers until a full health physics check has been conducted.</td>
<td></td>
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</tbody>
</table>

An active ventilation system would be required to provide forced ventilation to all areas of a GDF. Surface airborne activity may arise primarily from below ground areas due to radioactive gasses from the waste packages themselves. Gaseous radon, and consequently radon daughters, from natural sources may also be collected by the ventilation system. The rate of natural emanation will be dependant on the local geology. Therefore it is not possible at this stage to say what the radon natural emanation levels will be. However without forced ventilation, concentration levels may be comparable to those found in caves in the UK, the average of which has been measured to be 10,000 Becquerel/metre cubed (Bq/m$^3$) in the summer months when the temperature and pressure make radon emanation higher [29]. This would be above the 400 Becquerel/metre cubed (Bq/m$^3$) action level for workplaces in the UK [12]. It is a requirement of safety legislation that radon levels are tested. Radon levels can be lowered by a number of methods, e.g. sealing surfaces to minimise the emanation of radon or increasing ventilation rates to prevent radon build-up. It is estimated that if forced ventilation were established, providing one air change per hour, the concentration could be reduced by two orders of magnitude to around 100 Becquerel/metre cubed (Bq/m$^3$), which is below the action level.
Past studies have shown that although radon levels have been proven to be dependant on geology and ventilation, predicting radon levels within structures is unreliable and empirical measurement is the favoured method of assessment [30]. Therefore it is proposed that radon levels would be characterised during site characterisation prior to the final selection of a site. During the construction phase of the GDF a radon management programme would be developed. Areas of particular concern with regards to radon concentration levels may have worker access restricted until mitigation measures are implemented to reduce radon levels to an acceptable level, e.g. by increasing ventilation rates. Doses from naturally occurring radon are not considered further in this report.

The ventilation system will include High Efficiency Particulate in Air (HEPA) filtration and so the assessment of surface airborne contamination levels is based on the release of gaseous species only. Also, as the contribution from planned discharges from the maintenance facility for reusable transport containers is only a small fraction to the total airborne concentration, and would have a minor effect on operator illustrative doses [25], this contribution to airborne activity concentration is neglected. The contribution that discharges from the maintenance facility make to annual dose will however appear in future issues of this report.

As no maintenance schedule has been drawn up yet, no annual illustrative doses to maintenance personnel due to the accumulation of activity on filters and other plant items are calculated in this document. This will be revisited in later issues of the report when more information becomes available. There are a number of other operations for which annual illustrative dose rates have not yet been calculated because either there is not enough information available currently or because they involve either remote operations or no waste packages. These are outlined in Section 6 of this report.

Table 4 gives the other parameters required for calculating annual illustrative dose for specific locations and operations on the surface. For this report, exposure time estimates are based on values presented in GOSA, but are updated based on current thinking. The choice of an appropriate Bounding Hazards and Bounding Hazard factor is also taken from the GOSA.

Table 4 Table of surface scenario parameters

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Exposure hours per annum</th>
<th>Bounding Hazard</th>
<th>Bounding Hazard factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial visual inspection and collection from the gate area</td>
<td>500</td>
<td>BH N1</td>
<td>2</td>
</tr>
<tr>
<td>Waste packages, stationary rail wagons in rail sidings</td>
<td>1400</td>
<td>BH N2</td>
<td>4</td>
</tr>
<tr>
<td>Personnel conducting wagon decoupling (includes cover opening and package de-latching)</td>
<td>500</td>
<td>BH N1</td>
<td>1</td>
</tr>
<tr>
<td>Health Physics personnel conducting wagon inspection</td>
<td>500</td>
<td>BH N1</td>
<td>1</td>
</tr>
<tr>
<td>Maintenance personnel conducting track maintenance</td>
<td>not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste packages, heavy goods vehicle (HGV) loads in trailer park</td>
<td>1400</td>
<td>BH N2T</td>
<td>2</td>
</tr>
<tr>
<td>Maintenance personnel conducting maintenance activities</td>
<td>not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal operations in the trailer park: trailer decoupling</td>
<td>200</td>
<td>BH N1T</td>
<td>1</td>
</tr>
</tbody>
</table>
### Scenario

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Exposure hours per annum</th>
<th>Bounding Hazard</th>
<th>Bounding Hazard factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal operations in the trailer park: trailer inspection by heath physics personnel</td>
<td>200</td>
<td>BH N1T</td>
<td>1</td>
</tr>
<tr>
<td>Maintenance personnel conducting track maintenance</td>
<td>not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Illustrative dose to operators from open transport container in maintenance facility</td>
<td>not assessed</td>
<td>BH N8</td>
<td>1</td>
</tr>
<tr>
<td>Illustrative dose to operators from surface airborne contamination arising from aerial activity discharge via an active ventilation system (neglecting contribution from operations at the maintenance facility for reusable transport containers)</td>
<td>1400</td>
<td>BH N4</td>
<td>1</td>
</tr>
</tbody>
</table>

#### 3.3 Methodology for underground activities

The design for a GDF is a stand alone development on a single surface site. It comprises a number of basic below ground elements including:

- underground access
- ILW/LLW disposal area
- HLW/SF disposal area
- common services area.

The principal underground elements of a GDF are the vaults for the intermediate level waste (ILW)/LLW and depleted uranium (DU) and the disposal tunnels for the HLW/SF and Pu/highly enriched uranium (HEU).

Underground, the disposal areas for ILW/LLW and HLW/SF will be physically separated by at least 500m [8]. The construction and emplacement operations would be physically segregated with air locks between the working areas and would be serviced by separate underground roadways from the drift and shaft.

The vault sizes are geology dependent.

Underground areas were identified using the plans presented in the design reports [8]. These reports were then used to determine whether the operation would be manned or remote, and whether any waste packages would be in the area. Currently the illustrative dose has not been assessed in any underground facilities/rooms which may be contaminated but do not directly contain any waste packages. These may be revisited in later issues of this report when more information becomes available.

The principal manned components of the underground facility, the drift locomotive, SILW/LLW emplacement vault and the HLW/SF/Pu emplacement vault were selected for specific treatment. The methodology used to assess the illustrative dose rates in these areas is discussed below.

#### 3.3.1 Drift locomotive

For the higher strength and lower strength sedimentary rock concepts, a drift locomotive would be used to transport all the waste packages from the surface to the sub-surface, as well as transporting personnel. Personnel would not be transported at the same time as waste packages. However, the drift locomotive would be manned by a driver. There is potential for the drift locomotive driver to receive a dose from the packages he is...
transporting, however packages would not be removed from their transport containers until they are in their respective inlet cell or equivalent, which would be sub surface. Therefore, the dose rate from these packages will be consistent with transport limits.

Due to the geometry of the drift locomotive there would be significant shielding between the driver and the packages. It is expected that the waste packages would be transported along the drift using two locomotives with the driver present in the first locomotive, i.e. at the furthest point away from the waste packages. Therefore, substantial shielding would be provided by the locomotives. The dimensions of these locomotives are not known at this time. However, it would be expected that the driver would be at least ten metres from the waste packages.

It is assumed that the radiation dose rate of the packages is consistent with BH N2 i.e. that from a transport package at 10 m. The dose rate, without any allowance for the shielding provided by the locomotives, is therefore 0.005 millisievert/hour (mSv/h). It is also assumed that the locomotives provide a factor of 10 reduction to the dose rate based on the large amounts of steel in their construction. No credit has been taken for specific shielding that could be incorporated into the locomotive designs. The driver therefore is exposed to around 0.0005 millisievert/hour (mSv/h).

The drift is planned to be 4 km in length for the higher strength rock [8]. The maximum speed of this system is stated as being 20 kilometres per hour (km/hr) [8]. The duration of exposure per delivery of waste packages would be 24 minutes if the locomotive moved at 50% maximum speed or 16 minutes if it moved at 75% maximum speed.

The drift throughput is predicted to be 3,900 packages per year[8]. Only one package is transported on the drift train at a time. Assuming five shifts are required to account for staff illness and also assuming that there is only one operator per shift, the number of deliveries which must be made by a driver in one year is 780. Multiplying this number by the time it takes to make one delivery gives the annual exposure time for one shift worker.

Annual doses to drift maintenance personnel were presented in the GOSA. However due to uncertainties in the maintenance schedule updated estimates of these doses are not presented in this report, these will appear in later issues.

### 3.3.2 SILW/LLW emplacement

SILW waste packages are shielded and are transport packages in their own right. Due to their low surface dose rates they do not require remote handling. SILW packages are generally much heavier than unshielded intermediate level waste (UILW) packages and are placed directly, in separate vaults to the UILW, using a large capacity stacker truck.

Work performed within a previous assessment [31] calculated the radiation dose breakdown to a stacker truck driver in the higher strength rock during emplacement, where the emplacement face is the 95th percentile with regard to dose rate. The use of a 95th percentile face was chosen with a view to being more realistic than assuming a face made entirely of worst case packages, which would be overly pessimistic. In this assessment, the face was made entirely of four metre boxes as these represent a worst case with regard to external dose rate. If Windscale advanced gas-cooled reactor (WAGR) boxes and two metre boxes were to be included in the assessment, it is anticipated that annual doses would be reduced.

Initial calculations used a Monte-Carlo simulation to determine the 95th percentile radiation dose rate at a set distance from an array of stacked packages. A dose rate contour map was created of the SILW/LLW vault that was used to calculate the resultant illustrative dose rate to the stacker truck driver during emplacement.

The total radiation illustrative dose uptake to the stacker truck driver during emplacement was pessimistically assumed to result from the summation of:
• The radiation dose due to the stacker truck driver travelling to and from the face of the stored packages and the vault entrance
• The radiation dose due to a single four metre package present on the stacker truck (during travel to face and during emplacement on the stack)
• The radiation dose received whilst manoeuvring the stacker truck whilst the package is being placed into the stack of packages
• The internal radiation dose from the inhalation of radioactive containments in the vault atmosphere

In subsequent models for the lower strength sedimentary rock and evaporite a similar methodology is employed. However, only the two main contributors to illustrative doses were calculated i.e. the dose from a single package being present on the forks of the truck and the dose from manoeuvring in front of the face of packages whilst emplacement is being conducted. The contribution from the other factors (1 and 4 in the list above) was shown to be negligible and was not calculated for lower strength sedimentary rock and evaporite.

Table 5 outlines the dimensions of the vaults and the array sizes of four metre boxes.

Table 5  Geometry of SILW/LLW emplacement vault for the different vault geologies and size of package array

<table>
<thead>
<tr>
<th>Geology</th>
<th>Vault height (m)</th>
<th>Vault width (m)</th>
<th>Vault length (m)</th>
<th>Array height (No. packages)</th>
<th>Array width (No. packages)</th>
</tr>
</thead>
<tbody>
<tr>
<td>higher strength rock</td>
<td>15</td>
<td>16</td>
<td>300</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>lower strength rock</td>
<td>11.5</td>
<td>9.6</td>
<td>100</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>evaporite</td>
<td>5.5</td>
<td>10</td>
<td>90</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Buffer store
As SILW/LLW packages would arrive at an average rate of less than three per week, they would be stored underground until a sufficient number has accumulated for an efficient campaign of emplacement. Off loading of SILW and LLW packages from drift wagons into the buffer storage area would be conducted using an overhead travelling crane.

When sufficient packages have accumulated for an emplacement campaign, the packages would then be transferred via manned stacker truck to the SILW/LLW vault. It is assumed at this stage that a campaign would be around 20 to 30 packages.

The annual illustrative doses to operators making emplacements and removals within the buffer store may be assessed using the same methodology as that used for the illustrative dose to the stacker truck driver during emplacement within the SILW/LLW vault. This will be addressed in future issues of this report.

3.3.3  HLW/SF/Pu emplacement
HLW/SF and Pu/HEU would be packaged in disposal canisters offsite. It would be transported in a Disposal Canister Transport Container (DCTC) to the GDF and removed from the DCTC in the transfer station. The disposal tunnel technology is geology dependant. In the higher strength rock concept these packages are to be emplaced by an operator driving a shielded emplacement machine. Once a disposal canister has been placed in an

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2 This contribution was calculated assuming $5.11 \times 10^{-5}$ mSv/hr consistent with BH N5 in the GOSA
emplacement hole, then the hole would be capped with bentonite. When all emplacement holes in a tunnel are filled, the tunnel would then be filled with bentonite. The design of the emplacement machine would be such that it is sufficient to meet dose rate and as low as reasonably practicable (ALARP) targets during the emplacement of the disposal canisters.

There may be the possibility that post emplacement, during the backfill stage, the driver may experience a significant dose rate from the bentonite capped emplacement holes he is driving over. Some scoping work has been performed to assess the dose rate on the surface of a single emplacement hole after it is capped with 2.5 m of bentonite. As this is the first instance of these calculations being performed, the full methodology is presented. Calculations were performed extrapolating from the dose rate given by DIQuest\textsuperscript{3} at 3 m from the top of a HLW disposal canister (12.2 millisievert/hour (mSv/h)) to the dose rate given the additional bentonite shielding. The annual illustrative dose incurred during HLW/SF/Pu emplacement is discussed in Section 4.1.2 of this report.

A database and query tool, DIQuest, has been developed, which provides a derived Baseline Inventory\textsuperscript{4} for use in the risk assessment, chiefly by transforming data organised on a per stream basis into waste package based data. Data supplied from the DIQuest database shows that HLW represents the bounding case out of these three waste package types to be disposed of in the disposal tunnels, HLW, SF and Pu. The bounding waste stream was found to be 2F01/C, a HLW stream with dose rates of 1410 millisievert/hour (mSv/h), 94.3 and 0.236 millisievert/hour (mSv/h) at contact, 1 m and 3 m respectively when measured normal to the long axis of the Copper clad HLW disposal canister. The dose rate at 3 m from the top of the disposal canister was reported to be 12.2 millisievert/hour (mSv/h).

For the case of a lower strength sedimentary rock or evaporate facility, emplacement of HLW/SF/Pu is expected to be achieved by remote operations. The concept for the disposal of the HLW/SF/Pu packages in these geologies is that the individual canister is placed in the disposal tunnel and then the interspace between the tunnel walls and the canister backfilled with bentonite pellets or crushed evaporate as appropriate. Therefore the radiation exposure of workers during this emplacement process is expected to be negligible.

3.3.4 Other underground locations and operations

As was the case for the workers on the surface, the Bounding Hazards method was used to calculate the illustrative dose for other additional underground locations and operations. Table 6 presents dose rates for Bounding Hazards used for underground locations and operations.

The Bounding Hazard for underground airborne contamination is based on gas generation rates of $4 \times 10^{11}$ TBq per year for tritium, $4 \times 10^{18}$ TBq per year for Radon and $3 \times 10^{10}$ TBq per year for carbon 14, which come from the 2004\textsuperscript{28} inventory and a ventilation rate of \(23\text{m}^3\text{s}^{-1}\). These figures are from the gas generation report\textsuperscript{32} as used in the operational environmental safety assessment (OESA) to calculate doses to members of the public from routine GDF emissions. The figures used here are those appropriate for the SILW vaults, which may be accessed by underground workers.

It does not include a contribution from natural radon. Natural radon appears in the future work section of this report. The most significant difference between the 2001 inventory, 2004 inventory\textsuperscript{28} and the 2007 inventory\textsuperscript{18} with respect to the generation of gaseous radionuclides is the increased amount of depleted, natural and low enriched uranium (DNLEU) in the 2007 inventory. As Rn-222 and Rn-219 are present in the U-238

\textsuperscript{3} DIQuest is the NDA’s inventory database and query tool. The inventory used is the 2007 derived inventory [33].

\textsuperscript{4} As detailed in references [34,35,36].
and U-235 chains respectively, there is potential for increased gaseous radon contributions emanating from packages containing DNLEU. However, as uranium stored in the GDF will have undergone refinement, the presence of uranium daughters will be low. Due to the nature of U-238 decay, insufficient time has elapsed for significant amounts of Rn-222 to be generated.

More significant amounts of Rn-219 will be present from the U-235 decay chain. However, due to the short half-life of Rn-219 any delays or containment of the radon will result in the concentration of Rn-219 in the working area of the GDF becoming insignificant. Such containment may be provided by the waste package or by the physical form of the uranium itself. Similarly the air concentrations of Rn-222 from the DNLEU are expected to be low. For this reason no further modification of the Bounding Hazard derived in GOSA beyond those for the increases in ILW volumes in the 2004 inventory has been made at this stage.

Table 7 presents the other parameters required for calculating annual illustrative dose for underground locations and operations using this methodology. For this report, exposure time estimates have been updated based on available data.

**Table 6** Dose rates for Bounding Hazards, normal underground operations, updated with current thinking

<table>
<thead>
<tr>
<th>Bounding Hazard</th>
<th>Hazard description</th>
<th>Estimated dose rate to operator (mSv/hr) reference case</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>General$^{(1)}$</td>
</tr>
<tr>
<td>BH N2</td>
<td>External dose rate to worker 10 m from a package, in its transport configuration.</td>
<td>5.05 × 10^{-3}</td>
</tr>
<tr>
<td>BH N3</td>
<td>External dose rate to worker while in emplacement vehicle cab in SILW/LLW disposal area.</td>
<td>See Section 3.3.2 for detailed SILW/LLW emplacement methodology. Bounding Hazards are not used in the calculation of this dose.</td>
</tr>
<tr>
<td>BH N5</td>
<td>Worker dose rate for airborne contamination below ground, from routine operations.</td>
<td>5.7 × 10^{-5}</td>
</tr>
<tr>
<td>BH N7</td>
<td>HEPA filter-change operation - not evaluated because design is not finalised. Assumption is that design would incorporate ‘safe change’ filters and appropriate shielding.</td>
<td></td>
</tr>
<tr>
<td>BH N8</td>
<td>External dose to worker close to an open, empty reusable transport container for a short duration - not evaluated. The assumption is that normal operations would not allow operators near open and empty reusable transport containers until a full health physics check has been conducted.</td>
<td></td>
</tr>
<tr>
<td>BH N9</td>
<td>External dose through pipework – not evaluated because design is not finalised. Assumption is that design would provide adequate shielding.</td>
<td></td>
</tr>
</tbody>
</table>

Note:

1. General refers to all doses except for those incurred in the SILW/LLW and UILW vaults and also excludes the HLW disposal area. However, the ‘general’ dose rate is appropriate for HLW/SF/Pu whilst in its DCTC as it is assumed that dose rates will not exceed the assigned transport limit of 0.1 millisievert/hour (mSv/h) at 1 m. This would be consistent with the maximum dose rate at 1m from a type II yellow category package in accordance with the IAEA Regs. [17].
Table 7  Table of underground scenario parameters, with adjusted occupation times

<table>
<thead>
<tr>
<th>Location and operation</th>
<th>Exposure Hours per annum</th>
<th>Bounding Hazard</th>
<th>Bounding hazard factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drift; inspection/maintenance of the drift. Regular inspections would be carried out during non-emplacement shifts</td>
<td>TBC</td>
<td>BH N5</td>
<td>1</td>
</tr>
<tr>
<td>Inlet cell; illustrative dose incurred during inlet cell operations due to collection of packages in the buffer store</td>
<td>192</td>
<td>BH N2</td>
<td>2</td>
</tr>
<tr>
<td>Inlet cell; operational illustrative doses in inlet cell reception area. Operational area becomes contaminated by the cumulative effects of numerous package operations</td>
<td>1400</td>
<td>BH N5</td>
<td>1</td>
</tr>
<tr>
<td>Maintenance of ventilation ductwork (upstream of filters)</td>
<td>not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exchange of filters</td>
<td>TBC</td>
<td>BH N7</td>
<td>1</td>
</tr>
<tr>
<td>Maintenance activities conducted in active maintenance workshop-high level</td>
<td>not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance activities. Shielding of buffer store may be considered based on dose assessment. Maintenance activities include fork lift maintenance at vault access e.g. refuelling</td>
<td>not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal maintenance of ventilation system equipment</td>
<td>not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underground airborne contamination</td>
<td>1400</td>
<td>BH N5</td>
<td>1</td>
</tr>
<tr>
<td>Direct external illustrative dose from bowser, effluent tanks, etc</td>
<td>192</td>
<td>BH N9</td>
<td>1</td>
</tr>
<tr>
<td>External illustrative dose through pipework die to normal liquid effluent discharge from inlet cell activities</td>
<td>192</td>
<td>BH N9</td>
<td>1</td>
</tr>
<tr>
<td>External illustrative dose from vault contents through grout delivery pipe and borehole</td>
<td>TBC(^{(1)})</td>
<td>TBC(^{(2)})</td>
<td>1</td>
</tr>
<tr>
<td>Generation of washings and arisings</td>
<td>TBC(^{(3)})</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. Occasional inspection of delivery pipes and bore holes if required. Access would normally be restricted.
2. The choice of appropriate Bounding Hazard for this scenario will be made once the design of the pipe is more developed.
3. As indicated in Chapter 2 of the GOSA, the contributions from the normal effluent discharges have not been specifically assessed. It has been assumed that any dose from these sources would be minimised by the application of the ALARP principle.

3.4  Methodology for public illustrative doses

The only public illustrative dose within the scope of this report is the dose from packages, located at the surface facilities in transport containers before being moved underground. It
is not anticipated that large numbers of transport packages would be stockpiled above ground. However it is reasonable to expect that a train consisting of 12 wagons may be present on the surface. These wagons will have dose rates in compliance with the transport limits consistent with BH N1. An estimated bund thickness of 67m [21] was used. At this thickness dose rates due to transmission of the radiation through the bund are negligible, however skyshine doses resulting from the radiation being scattered in the atmosphere above the wagons, towards the public may be significant. A model using these input parameters was created in MCNP in order to estimate the illustrative dose rate at the site fence from the skyshine contribution.

3.5 Radiological dose targets

3.5.1 Applicable legislation and guidance

The approach adopted in the UK for the design of nuclear facilities is based on principles originally developed in the 1992 HSE publication ‘The Tolerability of Risk From Nuclear Power Stations’ (ToR) [33] and reiterated in the subsequent 2001 publication ‘Reducing Risks Protecting People’ (R2P2) [34]. In the Nuclear Installations Inspectorate (NII) Safety Assessment Principles (SAPs) [35], numerical targets and legal limits are set out. These are the Basic Safety Level (BSL) and the Basic Safety Objectives (BSO). The BSL marks the upper bound of the “tolerable” region and the BSO that for the “broadly acceptable” region of the HSE framework for risk management described in R2P2. The targets are not mandatory but some of the BSLs are the same as the legal limits in the Ionising Radiations Regulations 1999 (IRR99) [12].

It is Health and Safety Executive (HSE) policy that a new facility or activity should at least meet the BSLs [35]. However, in meeting the BSLs the risks may not be ALARP. The application of ALARP may drive risks lower. The SAPs contain the following explanation on the issue of ALARP:

“Deciding when the level of risk is ALARP needs to be made on a case by case basis. A proportionate approach should be used so that the higher the risk, the greater is the degree of disproportion needed before being considered ALARP, and a more robust argument would be needed to justify not implementing additional safety measures.” [35]

In considering the balance between cost and benefit the SAPs contain the following explanation on the issue of ALARP:

“The BSOs form benchmarks that reflect modern nuclear safety standards and expectations. The BSOs also recognise that there is a level beyond which further consideration of the case would not be a reasonable use of NII resources, compared with the benefit of applying the effort to other tasks. Inspectors need not seek further improvements from the duty holder but can confine themselves to assessing the validity of the arguments that the duty holder has presented. The duty holder, however, is not given the option of stopping at this level. ALARP considerations may be such that the duty holder is justified in stopping before reaching the BSO, but if it is reasonably practicable to provide a higher standard of safety, and then the duty holder should do so.” [35]

The Environment Agencies’ Geological Disposal Facilities on Land for Solid Radioactive Wastes, Guidance on Requirements for Authorisation (GRA) [36] sets out two further relevant principles and related criteria, the principles being:

**Principle 1 – Solid radioactive waste shall be disposed of in such a way that the level of protection provided to people and the environment against the radiological hazards of the**
waste both at the time of disposal and in the future is consistent with the national standard at the time of disposal; and

Principle 2 – Solid radioactive waste shall be disposed of in such a way that the radiological risks to individual members of the public and the population as a whole shall be as low as reasonably achievable under the circumstances prevailing at the time of disposal, taking into account economic and societal factors and the need to manage radiological risks to other living organisms and any non radiological hazards.

The GRA subsequently sets out dose constraints to be applied during the period of authorisation for disposal facilities. Dose constraints are defined in the GRA for members of the public and for the planning stages of the GDF. These dose constraints are not appropriate for this document which is concerned with annual doses to GDF workers during normal operation.

3.5.2 RWMD Policy Manual

The RWMD Radiological Protection Policy Manual [9] guides the design of a GDF by stating the applicable statutory limits (as given in IRR99). These limits are supplemented by more restrictive Design Targets which are used to guide designers. The Design Targets are appropriate to the types of activities envisaged for a GDF.

Table 1 of the Radiological Protection Policy Manual [9] provides the statutory limits together with the Design Targets for normal conditions of operation. Notes are appended to the table to indicate sources of criteria and any significant caveats or other information. This table is reproduced within this Normal Operations Operator Dose Assessment as Table 8.

Where it is reasonably practicable to reduce doses below the relevant Design Target or statutory limit, this must be done to satisfy ALARP considerations (see above). Design Targets have not been set for doses to the lens of the eye, skin and extremities at this stage in the conceptual design process, because it is considered there is insufficient information detail to identify any activities where these doses might be more limiting than the whole body dose.

For the purposes of this report a design dose target of an effective dose of 1 millisievert/year (mSv/y) will be applied.
Table 8  Dose limits and targets for normal operation [10]

<table>
<thead>
<tr>
<th></th>
<th>Employees of 18 years of age or above</th>
<th>Trainees (16-18y) (mSv/y)(4)</th>
<th>Any person other than an employee or trainee (including members of the public) (mSv/y)(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Employee working with ionising radiation (GDF) (mSv/y)</td>
<td>Other employees on site (mSv/y)(3)</td>
<td></td>
</tr>
<tr>
<td>Whole Body Doses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Statutory Effective Dose Limit(1)</td>
<td>20</td>
<td>20</td>
<td>6</td>
</tr>
<tr>
<td>Design Target(5)</td>
<td>1</td>
<td>0.1</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Statutory ‘Equivalent Dose Limits’ for lens of the eye, skin and extremities

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lens of eye</td>
<td>150</td>
<td>150</td>
<td>50</td>
</tr>
<tr>
<td>Skin(2)</td>
<td>500</td>
<td>500</td>
<td>150</td>
</tr>
<tr>
<td>Hands, forearms, feet and ankles</td>
<td>500</td>
<td>500</td>
<td>150</td>
</tr>
</tbody>
</table>

Notes:

1. The statutory effective dose limits are those lay down by Ionising Radiations Regulations 1999 (IRR99) Regulation 11 and Schedule 4 [12]. There are other dose limits and restrictions on exposure applicable to pregnant women, breast feeding mothers and women of reproductive capacity. (See IRR99 regulation 8(5) and Schedule 4). Underground work in a facility may entail enhanced exposure to naturally occurring radon gas and its daughter products (potentially a significant fraction of the worker’s total dose). Consequently this will lead to equivalent doses to the lungs and respective whole body effective dose. However the design of the ventilation system for the GDF would manage this effect and minimise the dose uptake. These doses shall be measured as part of routine operational dose monitoring of workers. Where the dose to workers from radon and its daughters is potentially significant, that dose is added to other occupational doses to calculate the total annual occupational dose (See IRR99 regulation 3 (1) (b)).

2. The limits for skin apply to the dose averaged over any area of 1 cm² regardless of the area exposed (See IRR99 Schedule 4) [12].

3. In the NII Safety Assessment Principles (SAPs), a distinction is made between ‘employees working with ionising radiations’ and ‘other employees on site’, with a lower BSL being set for the latter of 2 millisievert/year (mSv/y). No such distinction is made in the Ionising Radiations Regulations 1999 and all workers over 18 years of age on a site are subject to the same statutory dose limits. A lower design target is set for employees on site who are not radiation workers, consistent with the SAPs [35].

4. In IRR99 separate limits are prescribed for trainees less than 18 years of age. No Design Target is set as the limitation of dose for younger staff will be achieved by administrative controls and it is not intended to design specifically with trainees in mind.

5. These are the Basic Safety Objectives for normal operation defined in the NII SAPs [35].
4 Surface operator illustrative dose assessments

4.1 Surface facilities assessed using bounding hazards

Estimates of the routine exposure of workers undertaking various operations at the surface facilities are presented in Table 9. This table also presents Bounding Hazards from Table 3 and occupation times and hazard factors from Table 4 upon which the estimates are based and refers to the Design Target of 1 millisievert/year (mSv/yr) from Table 8 of this report.
<table>
<thead>
<tr>
<th>Surface facilities</th>
<th>Waste packages present</th>
<th>Remote operations</th>
<th>Bounding Hazard code and factor [Bounding Hazard value (mSv/y)]</th>
<th>Exposure Time (hours per annum)</th>
<th>Unmitigated Illustrative dose per annum (mSv/y)</th>
<th>Mitigated Illustrative dose per annum</th>
<th>Mitigation required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gate receipt area</td>
<td>Y</td>
<td>N</td>
<td>BH N1 – 2 [0.1]</td>
<td>500</td>
<td>100</td>
<td>Less than design target</td>
<td>The time required for inspections will need to be reduced in order to bring this illustrative dose to below the Design Target. There may also be some limited potential for remote operations in this area.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collection of waste packages, stationary rail wagons in rail sidings.</td>
<td>Y</td>
<td>N</td>
<td>BH N2 - 4 [0.005]</td>
<td>1400</td>
<td>30</td>
<td>Less than design target</td>
<td>Restricting access to this area would be required in order to bring the illustrative dose below the Design Target. Automation of decoupling.</td>
</tr>
<tr>
<td>Personnel conducting wagon de-coupling (includes cover opening and package de-latching).</td>
<td>Y</td>
<td>N</td>
<td>BH N1 - 1 [0.1]</td>
<td>500</td>
<td>50</td>
<td>eliminated</td>
<td>This illustrative dose is to be eliminated by using remote operations.</td>
</tr>
<tr>
<td>Surface facilities</td>
<td>Waste packages present</td>
<td>Remote operations</td>
<td>Bounding Hazard code and factor [Bounding Hazard value (mSv/y)]</td>
<td>Exposure Time (hours per annum)</td>
<td>Unmitigated Illustrative dose per annum (mSv/y)</td>
<td>Mitigated Illustrative dose per annum</td>
<td>Mitigation required</td>
</tr>
<tr>
<td>--------------------</td>
<td>------------------------</td>
<td>-------------------</td>
<td>---------------------------------------------------------------</td>
<td>-------------------------------</td>
<td>-----------------------------------------------</td>
<td>---------------------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Health Physics personnel conducting wagon inspection</td>
<td>Y</td>
<td>N</td>
<td>BH N1 - 1 [0.1]</td>
<td>500</td>
<td>50</td>
<td>Less than design target</td>
<td>This task will now be done in the transfer facility where the operator will be exposed to a single package rather than a whole wagon hence reducing this annual illustrative dose. There is also potential for some automation.</td>
</tr>
<tr>
<td>Collection of waste packages, Heavy goods vehicle (HGV) loads in trailer park.</td>
<td>Y</td>
<td>N</td>
<td>BH N2T – 2 [0.005]</td>
<td>1400</td>
<td>10</td>
<td>Less than design target</td>
<td>Restricting access to this area would be required in order to bring the illustrative dose below the Design Target</td>
</tr>
<tr>
<td>Normal operations in the trailer park: trailer de-coupling</td>
<td>Y</td>
<td>N</td>
<td>BH N1T – 1 [0.1]</td>
<td>200</td>
<td>20</td>
<td>Less than design target</td>
<td>Operation times must be reduced to a minimum, especially those in close proximity to a trailer, in order to bring this illustrative dose below the Design Target. Worker exposure in this scenario should be monitored.</td>
</tr>
<tr>
<td>Surface facilities</td>
<td>Waste packages present</td>
<td>Remote operations</td>
<td>Bounding Hazard code and factor [Bounding Hazard value (mSv/y)]</td>
<td>Exposure Time (hours per annum)</td>
<td>Unmitigated Illustrative dose per annum (mSv/y)</td>
<td>Mitigated Illustrative dose per annum</td>
<td>Mitigation required</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------------</td>
<td>------------------------</td>
<td>-------------------</td>
<td>-----------------------------------------------------------------</td>
<td>-------------------------------</td>
<td>-----------------------------------------------</td>
<td>--------------------------------------</td>
<td>--------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Normal operations in the trailer park: trailer inspection by Health Physics personnel</td>
<td>Y</td>
<td>N</td>
<td>BH N1T – 1 [0.1]</td>
<td>200</td>
<td>20</td>
<td>Less than design target</td>
<td>Operation times must be reduced to a minimum, especially those in close proximity to a trailer, in order to bring this illustrative dose below the Design Target. Worker exposure in this scenario should be monitored.</td>
</tr>
<tr>
<td>Illustrative dose to operators from surface airborne contamination arising from aerial activity discharge via an active ventilation system (neglecting operations at the maintenance facility for reusable transport containers)</td>
<td>Y</td>
<td>N</td>
<td>BH N4 – 1 [7.62×10⁻⁸]</td>
<td>1400</td>
<td>0.0001</td>
<td>N/A</td>
<td>This is based on a bounding scenario. No mitigation is currently suggested.</td>
</tr>
</tbody>
</table>
4.1.1 Shaft operators

The shaft would be used to transport spoil and equipment to and from the underground facility. In the case of the evaporite geology where there is no drift, an additional shaft would also be used to transport the waste packages to the underground facility. These packages would not be accompanied by personnel. Therefore unlike the drift, there is no ‘shaft driver’. Illustrative dose rates are therefore not calculated for the shaft for any of the three possible geologies.

4.1.2 Other surface buildings

Other buildings on the surface will be:

- rock crushing plant (construction area)
- explosives store (construction area)
- offices
- workshops and stores, and
- fire and rescue station.

These are not considered to be active areas and therefore illustrative dose rates in these areas will not be assessed.
5 Underground activity illustrative dose assessments

In this section the differences in operational illustrative doses due to different geologies and associated differing emplacement geometries are discussed.

5.1 Higher strength rock

5.1.1 Transfer of waste packages (higher strength rock)

Drift locomotive (higher strength rock)

Annual illustrative doses incurred by the drift locomotive driver due to packages being present on the drift train. Assumptions used to calculate this value are shown in Table 10.

Table 10 Annual illustrative dose incurred transporting packages through the drift, higher strength rock

<table>
<thead>
<tr>
<th>Drift</th>
<th>Waste packages present</th>
<th>Remote operations</th>
<th>Bounding Hazard Code and factor [Bounding Hazard value (mSv/y)]</th>
<th>Exposure time (hours per annum)</th>
<th>Assumed reduction factor due to shielding</th>
<th>Illustrative dose per annum (mSv/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locomotive moves at 50% max speed</td>
<td>Y</td>
<td>N</td>
<td>BH N2 - 1 [0.005]</td>
<td>312</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Locomotive moves at 75% max speed</td>
<td>Y</td>
<td>N</td>
<td>BH N2 - 1 [0.005]</td>
<td>208</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Inspection/maintenance of drift (higher strength rock)

In general, illustrative doses during maintenance tasks are not assessed in this report. However, the Fault and Hazard Schedule identified one personnel hazard that could occur during transport to the disposal area under normal conditions. This is the dose incurred during inspection/maintenance from ambient contamination during inspections of the drift. Annual illustrative doses incurred during drift inspection and assumptions used to calculate this value are shown in Table 11.
Table 11  Annual illustrative dose incurred during drift inspection, higher strength rock

<table>
<thead>
<tr>
<th>Drift</th>
<th>Waste packages present</th>
<th>Remote operations</th>
<th>Bounding Hazard Code and factor [Bounding Hazard value (mSv/y)]</th>
<th>Exposure time (hours per annum)</th>
<th>Illustrative dose per annum (mSv/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>N</td>
<td>BH N5 – 1 [5.× 10^{-5}]</td>
<td>TBC</td>
<td>TBC</td>
</tr>
</tbody>
</table>

Illustrative dose to inspection/maintenance personnel from ambient contamination

UILW inlet cell (higher strength rock)

The inlet cell is where each unshielded intermediate level waste (UILW) emplacement package would be removed from its reusable transport container and placed on a bogie for transport to the designated vault.

The inlet cell would be located underground to enable the waste packages to be transported in their robust reusable transport containers as close as possible to the point of emplacement. The cell would be shielded, and would also allow for the complete containment of any radioactive material in the unlikely event of an incident.

These inlet cells would be unmanned and viewed via Closed Circuit Television (CCTV) in all three geologies. It would be a concrete shell with shield doors and lead glass windows. Therefore it can be assumed that it is designed such that any doses to operators around the area outside the cell would be negligible.

Table 12 presents annual illustrative doses to inlet cell workers. It has been previously reported [25] that the dose to the inlet cell worker from the collection of waste packages in the buffer store would require mitigation. Without mitigation, the illustrative dose to the inlet cell worker from the collection of waste packages at the buffer store would be 2 millisievert/year (mSv/y). With increased shielding between the inlet cell and the buffer store, this annual illustrative dose can be reduced to below Design Targets.

Table 12  Annual illustrative doses incurred within inlet cell, higher strength rock

<table>
<thead>
<tr>
<th>Inlet Cell</th>
<th>Waste packages present</th>
<th>Remote operations</th>
<th>Bounding Hazard code and factor [Bounding Hazard value] (mSv/y)</th>
<th>Exposure Time (hours per annum)</th>
<th>Illustrative dose per annum (mSv/y)</th>
<th>Mitigation required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removal of package from transport container</td>
<td>Y</td>
<td>Y</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>
Illustrative dose to inlet cell operator from waste packages in buffer store

<table>
<thead>
<tr>
<th>Waste packages present</th>
<th>Remote operations</th>
<th>Bounding Hazard code and factor [Bounding Hazard value] (mSv/y)</th>
<th>Exposure Time (hours per annum)</th>
<th>Illustrative dose per annum (mSv/y)</th>
<th>Mitigation required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>n/a</td>
<td>BH N2 -2 [0.005]</td>
<td>192</td>
<td>2</td>
<td>Additional shielding between inlet cell and buffer store is required in order to bring the illustrative dose below the Design Target</td>
</tr>
</tbody>
</table>

Illustrative dose to inlet cell operator as inlet cell reception area becomes contaminated

<table>
<thead>
<tr>
<th>Package emplacement and retrieval within buffer store</th>
<th>Y</th>
<th>N</th>
<th>n/a</th>
<th>n/a</th>
<th>TBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package transport from buffer store to SILW/LLW vault</td>
<td>Y</td>
<td>N</td>
<td>n/a</td>
<td>n/a</td>
<td>TBC</td>
</tr>
</tbody>
</table>

SILW/LLW buffer store (higher strength rock)
The buffer store is an area which contains packages and is an area where remote operations would not be employed. Due to the distances involved this may be a contributor to the annual dose which has not been accounted for. Table 13 below summarises the scenario. The annual illustrative dose due to transferring the package from the buffer store to the vault entrance will be presented in future issues of this report.

Table 13  Annual illustrative dose to operators conducting transports involving the buffer store, higher strength rock

<table>
<thead>
<tr>
<th>SILW/LLW Buffer store</th>
<th>Waste packages present</th>
<th>Remote operations</th>
<th>Dose rate (mSv/h)</th>
<th>Exposure time (hours per annum)</th>
<th>Illustrative dose per annum (mSv/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package emplacement and retrieval within buffer store</td>
<td>Y</td>
<td>N</td>
<td>n/a</td>
<td>n/a</td>
<td>TBC</td>
</tr>
<tr>
<td>Package transport from buffer store to SILW/LLW vault</td>
<td>Y</td>
<td>N</td>
<td>n/a</td>
<td>n/a</td>
<td>TBC</td>
</tr>
</tbody>
</table>
HLW/SF transfer station (higher strength rock)

In the higher strength rock facility, the high level waste (HLW), spent fuel (SF), highly enriched uranium (HEU) and plutonium (Pu) would be removed from its transport container in this transfer station. The transfer station would transfer the canisters from the Disposal Canister Transport Container (DCTC) and the drift locomotive used to transport packages from the surface to the underground, onto a transport system serving the underground disposal tunnels. This operation would be undertaken using a 60 tonne crane. It would be arranged to reverse into the facility and the drift locomotive would be uncoupled and removed from the area. The operations are controlled from a local control room equipped with a CCTV system to monitor all operations. The disposal canister would then be put into a shielded deposition machine to be taken to the disposal tunnel [8].

The transfer station will be designed such that any doses to operators around the area outside the transfer station would be negligible. Table 14 summarises the fact that as this area involves remote operation, no annual illustrative dose is calculated. Following transfer in this area, the disposal canister would then be put into a shielded deposition machine to be taken to the disposal tunnel.

Table 14  Annual illustrative dose incurred whilst removing HLW/SF from transport containers, higher strength rock

<table>
<thead>
<tr>
<th>HLW/SF transfer Station</th>
<th>Waste packages present</th>
<th>Remote operations</th>
<th>Illustrative dose per annum (mSv/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package removal from transport container</td>
<td>Y</td>
<td>Y</td>
<td>n/a</td>
</tr>
</tbody>
</table>

5.1.2 Emplacement of waste packages (higher strength rock)

SILW/LLW (higher strength rock)

These packages would be emplaced manually in a vault by an operator driving a stacker truck [8]. In the case of the higher strength rock the annual illustrative dose rates are predicted to be 0.9 millisievert/year (mSv/y) [31].

Predicted doses to stacker truck drivers are 90% of the Design Target dose for employees ‘working with ionising radiation’, and less than 5% of the statutory dose limit.

Doses to stacker truck drivers during emplacement could be reduced through shielding of the cab (such as lead glass windows, lead lined footwell/dashboard), optimising vehicle speeds and routes to reduce driving times, training or extending the length of the arm on the stacker truck to increase driver-package distance. An as low as reasonably practicable (ALARP) assessment including engineering options will be undertaken to identify the most appropriate course of action. The annual illustrative dose to an operator emplacing packages in the shielded intermediate level waste (SILW) / low level waste (LLW) vault within a higher strength rock is shown in Table 15.

Table 15  Annual illustrative dose incurred emplacing packages in the SILW/LLW vault, higher strength rock

<table>
<thead>
<tr>
<th>SILW/LLW vault</th>
<th>Waste packages present</th>
<th>Remote operations</th>
<th>Illustrative dose per annum (mSv/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package Emplacement</td>
<td>Y</td>
<td>N</td>
<td>0.9</td>
</tr>
</tbody>
</table>
UILW (higher strength rock)

Unshielded intermediate level waste (UILW) emplacement units would be transported from the inlet cell to the vaults via a dedicated transfer tunnel. The transfer tunnel would contain a single bogie track and would pass through the end of each of the UILW vaults, where a shielded plug in the roof of the tunnel would give access to the vault. The package on the bogie would be moved by remote control, to stop beneath the shielded plug of the destination vault. This plug would be removed and the vault crane would lift the unit up into the vault for emplacement [8]. It can be assumed that the UILW vault and remote operation control area is designed such that any doses to operators would be negligible.

Emplacement within the vaults would be by a 20 tonne overhead travelling crane running the full length of the vault. At the end of each vault there will be a crane maintenance area that will be shielded from the waste by a mobile shield door. Emplacement would start from the far end of the vault and work back towards the access hatch. The basic stacking array across the vault cross section will be seven packages wide, and seven high. Emplacement stillages holding four 500 litre drums will be stacked in columns of seven. The 3m$^3$ boxes and 3m$^3$ drums will be mix-stacked together in columns of seven. Table 16 summarises the scenario in this area and highlights that no annual illustrative dose is calculated for this as it is a remote operation.

Table 16  Annual illustrative dose to operators emplacing UILW, higher strength rock

<table>
<thead>
<tr>
<th>UILW vault</th>
<th>Waste packages present</th>
<th>Remote operations</th>
<th>Dose rate (mSv/h)</th>
<th>Exposure time (hours per annum)</th>
<th>Illustrative dose per annum (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emplacement of UILW packages</td>
<td>Y</td>
<td>Y</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

HLW/SF/Pu/HEU (higher strength rock)

The transfer of HLW/SF/Pu/HEU canisters from the DCTC would take place at the HLW/SF transfer station discussed above. The disposal canister would then be put into a manned, shielded deposition machine to be taken to the disposal tunnel. These packages would be emplaced manually by the operator driving the shielded disposal vehicle. Table 17 summarises this scenario. However, as at this stage specific data regarding the performance of the emplacement vehicle is not available, annual illustrative doses for canister emplacement cannot be calculated.

Table 17  Annual illustrative dose incurred whilst emplacing HLW/SF/Pu/HEU, higher strength rock

<table>
<thead>
<tr>
<th>HLW/SF/Pu disposal tunnel</th>
<th>Waste packages present</th>
<th>Remote operations</th>
<th>Exposure time (hours per annum)</th>
<th>Illustrative dose per annum (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emplacement of HLW/SF/Pu packages</td>
<td>Y</td>
<td>N</td>
<td>TBC</td>
<td>TBC</td>
</tr>
</tbody>
</table>

In order to assess the illustrative dose during the back filling stage, dose rates were extracted from DIQuest for a distance of 3m above a copper canister. It was seen the HLW was the bounding case at 12.2 millisievert/hour (mSv/h). The geometry for this scenario is shown in Figure 2 below. By using the shielding code Microshield the dose rate from this same package with a 2.5m bentonite plug between the canister and dose point was calculated to be trivial.
Details of the design of the deposition vehicle are not available at this time. However, it can be assumed that the driver of the deposition vehicle would be at a distance above the deposition hole. It is also assumed the driver would be shielded from the waste packages in the holes beneath the vehicle, to some extent, by the deposition vehicle itself.

The corresponding dose rates at distances above the deposition hole entrance may be approximated by assuming that dose rate falls as a function of the distance squared \([37]\). It is reasonable to assume that a case for manual back filling of the disposal tunnel can be made, indeed the dose per hour can be seen to be trivial. It is assumed that the shielding would be designed such that the annual dose rates will be ALARP. Table 18 presents a summary of this scenario.

### Table 18  Annual illustrative dose incurred whilst backfilling HLW/SF/Pu/HEU disposal tunnel, higher strength rock

<table>
<thead>
<tr>
<th>HLW/SF/Pu disposal tunnel</th>
<th>Waste packages present</th>
<th>Remote operations</th>
<th>Exposure time (hours per annum)</th>
<th>Illustrative dose per hour (mSv)</th>
<th>Mitigation required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backfilling of HLW/SF/Pu/HEU disposal tunnel</td>
<td>Y</td>
<td>N</td>
<td>TBC</td>
<td>Trivial</td>
<td>It is expected the emplacement vehicle would provide sufficient shielding. No further shielding would be required.</td>
</tr>
</tbody>
</table>
5.1.3 Underground airborne contamination (higher strength rock)

Table 19 summarises the input parameters and presents the annual illustrative dose to underground workers from airborne contamination.

### Table 19 Annual illustrative dose to operators due to underground airborne contamination, higher strength rock

<table>
<thead>
<tr>
<th>Underground</th>
<th>Waste packages present</th>
<th>Remote operations</th>
<th>Bounding Hazard code</th>
<th>Exposure time (hours per annum)</th>
<th>Illustrative dose per annum (mSv)</th>
<th>Mitigation required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrespective of activity</td>
<td>Y</td>
<td>N</td>
<td>BH N5</td>
<td>1400 [5.52× 10^{-5}]</td>
<td>0.08</td>
<td>No mitigation is currently suggested.</td>
</tr>
</tbody>
</table>

5.1.4 Areas not containing waste packages (higher strength rock)

There would be a number of other underground areas that do not at any point contain waste packages and therefore in normal operation, assuming no contamination, these should not be active areas. Therefore no illustrative doses are calculated in these areas. These are namely the:

- UILW Bogie Decontamination Cell, a manual process undertaken by swabbing or high pressure water hoses
- UILW Effluent Sampling laboratory, Receipt and Dispatch
- truck and locomotive garages
- backfill batching area
- workshop
- storage hall
- personnel hall
- battery charging area
- spoil bunker
- rock drainage hall
- mines rescue room
- various ventilation plant rooms.

5.1.5 Conclusions regarding higher strength rock annual illustrative doses

Table 20 summarises the annual illustrative dose to various workers for the higher strength rock facility.

### Table 20 Annual illustrative dose summary, higher strength rock

<table>
<thead>
<tr>
<th>Underground facilities</th>
<th>Annual illustrative dose (mSv/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drift Locomotive</td>
<td>0.2</td>
</tr>
<tr>
<td>Inspection of drift</td>
<td>TBC</td>
</tr>
<tr>
<td>Removal from transport container in inlet cell</td>
<td>n/a</td>
</tr>
</tbody>
</table>
It is anticipated that an individual would not perform all the tasks identified above. The task resulting in the maximum illustrative dose received by an underground worker is expected to be the emplacement of SILW packages, as mitigation is to be applied to reduce the dose to the inlet cell worker from the collection of waste packages in the buffer store. The stacker truck driver is predicted to incur an exposure of 0.9 millisievert/year (mSv/y) from this task. This illustrative dose is within the design dose rate target of 1 millisievert/year (mSv/y). However the implementation of simple measures, such as training, will be investigated to ensure that this exposure is made ALARP. It can also be seen that based on initial design specification the drift locomotive driver would also receive an annual illustrative dose that is a significant proportion of the Design Target. It is suggested that this calculation is revisited when more detailed specifications regarding the construction and operation of the locomotive are available.

5.2 Lower strength sedimentary rock

Illustrative doses will only be discussed in this section where they vary from those in the higher strength rock (discussed in Section 4.1).

5.2.1 Transfer of waste packages (lower strength sedimentary rock)

Drift locomotive (lower strength sedimentary rock)

The length of the drift shaft is different to that for higher strength rock, only 3.3km compared to 4km in the higher strength rock. All other parameters such as locomotive speed and number of deliveries per year remain the same in the lower strength sedimentary rock as for the higher strength rock. Therefore any illustrative doses to the drift train driver would be lower for the lower strength sedimentary rock facility. As the shaft is 17% shorter in this lower sedimentary rock geology, a 17% reduction in illustrative dose for this scenario is assumed. This would result in an illustrative dose of 0.17 millisievert/year (mSv/y) for this scenario. It was not deemed appropriate to perform detailed modelling of this dose at this time.

SILW/LLW buffer store (lower strength sedimentary rock)

The SILW/LLW buffer store in the lower strength sedimentary rock may be of different dimensions to that for the higher strength rock. As was the case for the higher strength

<table>
<thead>
<tr>
<th>Underground facilities</th>
<th>Annual illustrative dose (mSv/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet cell, illustrative dose from collection of waste packages in buffer store</td>
<td>&lt; Design Target after mitigation</td>
</tr>
<tr>
<td>Inlet cell, illustrative dose as inlet cell reception area becomes contaminated</td>
<td>0.08</td>
</tr>
<tr>
<td>Buffer store, package emplacement and retrieval within buffer store</td>
<td>TBC</td>
</tr>
<tr>
<td>Package transport from buffer store to SILW/LLW vault</td>
<td>TBC</td>
</tr>
<tr>
<td>Removal of HLW/SF disposal canister from transport container</td>
<td>n/a</td>
</tr>
<tr>
<td>SILW/LLW emplacement in vault</td>
<td>0.9</td>
</tr>
<tr>
<td>UILW emplacement</td>
<td>n/a</td>
</tr>
<tr>
<td>HLW/SF emplacement</td>
<td>TBC</td>
</tr>
<tr>
<td>HLW/SF disposal tunnel backfill</td>
<td>&lt; Design Target, no mitigation required</td>
</tr>
<tr>
<td>Underground, airborne contamination</td>
<td>0.08</td>
</tr>
</tbody>
</table>
rock, packages would be manually placed and removed from this area and hence there would be an annual operator dose. The same methodology used to calculate illustrative dose rates for the stacker truck driver could be used to calculate these illustrative doses, and this may be done in future issues of this report. Table 20 presents a summary of this scenario.

Table 21 Annual illustrative dose to operators conducting transports involving the buffer store, lower strength sedimentary rock

<table>
<thead>
<tr>
<th>SILW/LLW Buffer store</th>
<th>Waste packages present</th>
<th>Remote operations</th>
<th>Dose rate (mSv/h)</th>
<th>Exposure time (hours per annum)</th>
<th>Illustrative dose per annum (mSv/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package emplacement and retrieval within buffer store</td>
<td>Y</td>
<td>N</td>
<td>n/a</td>
<td>n/a</td>
<td>TBC</td>
</tr>
<tr>
<td>Package transport from buffer store to SILW/LLW vault</td>
<td>Y</td>
<td>N</td>
<td>n/a</td>
<td>n/a</td>
<td>TBC</td>
</tr>
</tbody>
</table>

5.2.2 Emplacement of waste packages (lower strength sedimentary rock)

SILW/LLW (lower strength sedimentary rock)

In the lower strength sedimentary rock the SILW/LLW storage vaults are different dimensions to those for the higher strength rock. The annual illustrative dose rate is lower due to the smaller emplacement face and the reduced travel time to face. The annual illustrative dose rate to the operator in this instance is calculated to be 0.122 millisievert/year (mSv/y).

Predicted doses to stacker truck drivers in the lower strength sedimentary rock geology are just 12% of the Design Target dose for employees 'working with ionising radiation', and less than 1% of the statutory dose limit.

As for the higher strength rock, illustrative doses to stacker truck drivers could be reduced through shielding of the cab (such as lead glass windows, lead lined footwell/dashboard), optimising vehicle speeds and routes to reduce driving times or extending the length of the arm on the stacker truck to increase driver-package distance.

Table 22 summarises the assumptions and annual illustrative dose to the stacker truck driver carrying out SILW/LLW vault emplacement operations in the lower strength sedimentary rock.

Table 22 Annual illustrative dose incurred emplacing packages in the SILW/LLW vault, lower strength sedimentary rock

<table>
<thead>
<tr>
<th>SILW/LLW vault</th>
<th>Waste packages present</th>
<th>Remote operations</th>
<th>Illustrative dose per annum (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stacker truck driver</td>
<td>Y</td>
<td>N</td>
<td>0.122</td>
</tr>
</tbody>
</table>

HLW/SF/Pu (lower strength sedimentary rock)

Unlike in the higher strength rock scenario, the tunnels for the deposition of HLW/SF/Pu packages in the lower strength sedimentary rock would be remotely filled and backfilled. The following extract taken from [21] describes in more detail the remote operation.
The HLW/SF/Pu disposal tunnel transfer would allow transfer of the disposal canisters from the DCTC that arrives on a drift locomotive, from the surface to the underground, onto a disposal trolley. A dedicated reception area would be provided at each of the disposal tunnels, equipped with shield door at both ends to provide protection for personnel.

Following receipt of the DCTC and uncoupling of the drift locomotive the outer shield door is closed and transfer operations would be undertaken remotely. A support bed with integral handling equipment would be used to remove the DCTC shock absorbers and lid to allow the disposal canister to be withdrawn and lifted onto the bentonite support blocks previously placed on the disposal trolley. The inner shield doors are opened and the disposal trolley transfers the disposal canister and supporting benonite blocks to the required location and lowers them onto the floor. The disposal trolley is withdrawn and the inner shield door closed. The DCTC lid and shock absorbers are replaced and the outer shield doors are opened to allow removal of the DCTC and the disposal trolley.

The area of the disposal tunnel around the disposal canister would be filled with bentonite pellets immediately after placement of the disposal canister. On arrival underground the bentonite pellets would be transferred to a mobile hopper. The mobile hopper with locomotive attached would be transferred to the reception area of the disposal tunnel and the outer shield door closed.

The inner shield door would be opened and the mobile hopper would be detached from the locomotive and moved to the far end of the disposal tunnel over the disposal canister that had just been emplaced. The bentonite pellets would be discharged to fill the area beyond the disposal canister and would then be gradually withdrawn to fill the area all around the disposal canister. The mobile hopper would then be withdrawn to the reception area, connected to the locomotive and the inner shield door closed.

The outer shield door would then be opened and the locomotive and mobile hopper would be moved to the bentonite pellet loading facility to allow the next batch of bentonite pellets to be loaded.

The above cycle would be repeated until the disposal tunnel is filled with disposal canisters on bentonite support blocks with bentonite pellets filling the remaining voids.

It can be assumed that this part of the facility is designed such that any doses to operators around the area outside the disposal tunnel would be negligible.

5.2.3 Conclusions regarding lower strength sedimentary rock annual illustrative doses

Table 23 summarises the annual illustrative dose to various workers involved in operations within the lower strength sedimentary rock facility.

<table>
<thead>
<tr>
<th>Underground facilities</th>
<th>Annual illustrative dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drift Locomotive</td>
<td>0.2</td>
</tr>
<tr>
<td>Inspection of drift</td>
<td>TBC</td>
</tr>
<tr>
<td>Removal from transport container in inlet cell</td>
<td>n/a</td>
</tr>
<tr>
<td>Inlet cell, illustrative dose from waste packages in buffer store</td>
<td>&lt; Design Target after mitigation</td>
</tr>
<tr>
<td>Inlet cell, illustrative dose as inlet cell reception area becomes contaminated</td>
<td>0.08</td>
</tr>
</tbody>
</table>
Unlike the higher strength rock scenario, the task resulting in the maximum individual illustrative dose received by an underground worker is expected to be that to the drift locomotive driver, the second largest illustrative dose is that received during the emplacement of SILW. The annual illustrative dose is within the Design Target, however consideration will be made to taking measures such as the provision of shielding to reduce this dose to ALARP. The annual illustrative dose to the SILW/LLW emplacement operator is reduced in this geology compared to that of the higher strength rock. The annual illustrative dose to the drift locomotive driver is also comparable of that to the SILW/LLW emplacement operator however the calculation of the annual illustrative dose to the locomotive driver will be revisited when more detailed specifications regarding the construction and operation of the locomotive are available.

### 5.3 Evaporite

#### 5.3.1 Transfer of waste packages (evaporite)

**Drift locomotive (evaporite)**

Unlike the higher strength and lower strength sedimentary rock scenarios, in the evaporite scenario there is no drift, therefore there is no drift train operator for which an annual illustrative dose needs be calculated. Instead, all access to underground is via one of four vertical shafts. The four shafts would be unmanned and so this exposure route has been eliminated.

**SILW/LLW buffer store (evaporite)**

The SILW/LLW buffer store in the evaporite rock may be of different dimensions to that for the higher strength rock. As was the case for the higher strength rock, packages would be manually placed and removed from this area and hence there would be an annual operator dose. The same methodology used to calculate illustrative dose rates for the stacker truck driver could be used to calculate these illustrative doses, and this is recommended for future issues of this report. Table 24 presents a summary of this scenario.

Table 24 Annual illustrative dose to operators conducting transports involving the buffer store, evaporite

<table>
<thead>
<tr>
<th>SILW/LLW Buffer store</th>
<th>Waste packages present</th>
<th>Remote operations</th>
<th>Illustrative dose per annum (mSv/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package emplacement and retrieval within buffer store</td>
<td>Y</td>
<td>N</td>
<td>TBC</td>
</tr>
<tr>
<td>Package transport from buffer store to SILW/LLW vault</td>
<td>Y</td>
<td>N</td>
<td>TBC</td>
</tr>
</tbody>
</table>
5.3.2 Emplacement of waste packages (evaporite)

**SILW/LLW (evaporite)**

The dimensions of the SILW/LLW vault are different for each of the three geologies. However the distance travelled in this evaporite scenario is similar to that in the lower strength sedimentary rock. The emplacement face in this scenario is smaller due to the smaller vault cross section and the need to keep a constant backfill ratio. As a result the annual illustrative dose is also smaller in this evaporite scenario at 0.1 millisievert/year (mSv/y). This is summarised in Table 25.

Predicted doses to stacker truck drivers in the evaporite facility are just 12% of the Design Target dose for employees ‘working with ionising radiation’, and less than 1% of the statutory dose limit.

As was the case for the other geologies, illustrative doses to stacker truck drivers could be reduced through shielding of the cab (such as lead glass windows, lead lined footwell/dashboard), optimising vehicle speeds and routes to reduce driving times or extending the length of the arm on the stacker truck to increase driver-package distance.

**Table 25** Annual illustrative dose to the SILW/LLW stacker truck driver emplacing packages in the SILW/LLW vault, evaporite

<table>
<thead>
<tr>
<th>SILW/LLW vault</th>
<th>Waste packages present</th>
<th>Remote operations</th>
<th>Illustrative dose per annum (mSv/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stacker truck driver</td>
<td>Y</td>
<td>N</td>
<td>0.1</td>
</tr>
</tbody>
</table>

**HLW/SF/Pu (evaporite)**

Like the lower strength sedimentary rock scenario, the tunnels for the deposition of HLW/SF/Pu packages in the evaporite rock would be remotely filled and backfilled. The main difference in the evaporite rock is that the DCTC would be transferred below ground via a shaft rather than a drift. The following describes in more detail the remote operation.

A dedicated reception area would be provided at each of the disposal tunnels, equipped with shield door at both ends to provide protection for personnel.

Following receipt of the DCTC and uncoupling of the drift locomotive the outer shield door is closed and transfer operations would be undertaken remotely. A support bed with integral handling equipment would be used to remove the DCTC shock absorbers and lid to allow the disposal canister to be withdrawn and transferred to an emplacement frame. The inner shield doors are opened and the emplacement frame transfers the disposal canister to the required location and lowers it onto the floor. The emplacement frame is withdrawn and the inner shield door closed. The DCTC lid and shock absorbers are replaced and the outer shield doors are opened to allow removal of the DCTC and the disposal trolley.

The area of the disposal tunnel around the disposal canister would be filled with crushed evaporite immediately after placement of the disposal canister. On arrival underground the crushed evaporite would be transferred to a mobile hopper. The mobile hopper with locomotive attached would be transferred to the reception area of the disposal tunnel and the outer shield door closed.

The inner shield door would be opened and the mobile hopper would be detached from the locomotive and moved to the far end of the disposal tunnel over the disposal canister that had just been emplaced. The crushed evaporite would be discharged to fill the area beyond the disposal canister and would then be gradually withdrawn to fill the area all around the...
disposal canister. The mobile hopper would then be withdrawn to the reception area, connected to the locomotive and the inner shield door closed.

The outer shield door would then be opened and the locomotive and mobile hopper would be moved to the crushed evaporite loading facility to allow the next batch of crushed evaporite to be loaded.

The above cycle would be repeated until the disposal tunnel is filled with disposal canisters on stands with crushed evaporite filling the remaining voids.

It can be assumed that this part of the facility is designed such that any doses to operators around the area outside the disposal tunnel would be negligible.

5.3.3 Conclusions regarding evaporite annual illustrative doses

Table 26 summarises the annual illustrative dose to various workers involved in operations in the evaporite facility.

Table 26 Annual illustrative dose summary, evaporite

<table>
<thead>
<tr>
<th>Underground facilities</th>
<th>Annual illustrative dose (mSv/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drift Locomotive</td>
<td>n/a</td>
</tr>
<tr>
<td>Inspection of drift</td>
<td>TBC</td>
</tr>
<tr>
<td>Removal from transport container in inlet cell</td>
<td>n/a</td>
</tr>
<tr>
<td>Inlet cell, illustrative dose from waste packages in buffer store</td>
<td>&lt; Design Target after mitigation</td>
</tr>
<tr>
<td>Inlet cell, illustrative dose as inlet cell reception area becomes contaminated</td>
<td>0.08</td>
</tr>
<tr>
<td>Buffer store, package emplacement and retrieval within buffer store</td>
<td>TBC</td>
</tr>
<tr>
<td>Package transport from buffer store to SILW/LLW vault</td>
<td>TBC</td>
</tr>
<tr>
<td>SILW/LLW emplacement in vault</td>
<td>0.1</td>
</tr>
<tr>
<td>HLW/SF emplacement</td>
<td>n/a</td>
</tr>
<tr>
<td>HLW/SF disposal tunnel backfill</td>
<td>n/a</td>
</tr>
<tr>
<td>Underground, airborne contamination</td>
<td>0.08</td>
</tr>
</tbody>
</table>

As with the higher strength rock the maximum task illustrative dose received by an underground worker in the evaporite geology is expected to be that received during the SILW/LLW emplacement.

Consideration will be made to taking measures such as the provision of shielding to reduce this dose to ALARP. Summary of annual illustrative doses and comparison of the three different geologies are presented in Table 27.
6 Public illustrative dose assessments

The regulation of public doses during the operation of a GDF is split between the Environment Agency (EA) and NII. The EA regulates doses to members of the public from site discharges. The NII regulates doses to members of the public from direct radiation emitted from sources on the site. Therefore direct radiation doses to members of the public are considered here and doses from site discharges are addressed in the OESA [10].

During normal operations there are two potentially bounding sources of external radiation which can lead to doses to the public: the lorry trailer park and the rail sidings where rail wagons are parked pending uncoupling and transfer to the waste receipt building.

The lorry trailer park has capacity for 26 trailers but most of these will be taken by trailers not in use or being returned empty to the waste originator and as a ‘just in time’ delivery regime is to be operated, it is unlikely that more than six (one day’s throughput) loaded transport containers will be present at any given time. For generic layouts considered the trailer park is further from the site boundary than the rail sidings and hence, for a given package, would give lower direct radiation to a member of the public than the rail sidings. For these reasons, the trailer park is not considered to be bounding for direct radiation doses to members of the public.

The rail sidings have the capacity to hold one week’s delivery (by rail) with additional capacity for the assembly of empty wagons into trains ready for despatch. During normal operations, only one train of twelve wagons is expected to occupy the sidings at any given time. It is expected to take about two days to process a train of twelve wagons, so the average continuous occupancy of the rail sidings during normal operations would be six wagons with a conservative bounding maximum of twelve wagons continuous occupancy.

Therefore, the greatest potential source of direct radiation to a member of the public would be from a train of 12 wagons, each loaded with a transport container emitting 0.1mSv per hour at 1m (the transport limit) parked in the siding closest to the site boundary. Members of the public are shielded from the rail sidings by a bund constructed of spoil from the construction of the GDF.

The NII’s Technical Assessment Guide T/AST/043 [38] requires an assessment of the dose to a member of the public who lives in the closest residence to the site assuming 100% occupancy or, for a remote site, a member of the public using the area at the site boundary for recreational purposes.

As no site has been selected it is impossible to know how far away from the railway sidings the nearest dwelling will be, or in which direction. Because of this no assessment for the occupants of such a property has been made. When a site has been selected a meaningful assessment based on the specific site geography will be made.

Once a GDF site has been identified, the design will be influenced by public doses, using local habit and occupancy data but in this report an illustrative example has been assessed. In this case a realistic assumption based on the illustrative concept surface facilities design is to assume an individual spends approximately 1 hour per day walking their dog at the external site fence (about 300m from the closest rail siding through the intervening bund). Under these conditions the direct radiation dose through the bund is trivial but the skyshine dose rate contribution is estimated to be $1 \times 10^{-5}$ mSv/hr, giving an annual illustrative dose of $4 \times 10^{-5}$mSv per year. This is well within the design target of 0.01mSv per year.

This dose to the public would be in addition to any incurred from normal operational site discharges that are reported as 0.052mSv per year in the OESA [10]. Normally summation of the two doses would give the total public dose but, because the points of origin of the
doses in the illustrative conceptual design are separated by a considerable distance and their final positional relationship undecided, it is considered inappropriate to do so at this stage. In practice, a site specific design would endeavour to ensure that the design target dose of 0.01mSv per year would be met.
7 Discussion and conclusion

Scoping assessments of illustrative doses to operators from normal operations in a geological disposal facility (GDF) have identified areas of potentially significant illustrative doses, in particular from manual operations, requiring operators to be in close proximity to the transport packages for significant periods of time. Table 27 is a summary of the annual illustrative dose rates presented within this report. The descriptions mirror both those of the Generic Operational Safety Assessment (GOSA).

Table 27 Annual illustrative dose summary

<table>
<thead>
<tr>
<th>Surface facilities</th>
<th>Higher strength rock</th>
<th>Lower strength sedimentary rock</th>
<th>Evaporite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial visual inspection and collection from the gate area</td>
<td>&lt; Design Target (after reducing time required for inspections)</td>
<td>&lt; Design Target (after reducing time required for inspections)</td>
<td>&lt; Design Target (after reducing time required for inspections)</td>
</tr>
<tr>
<td>Illustrative dose to site personnel (siding workers), waste packages in rail sidings</td>
<td>&lt; Design Target (after restricting access)</td>
<td>&lt; Design Target (after restricting access)</td>
<td>&lt; Design Target (after restricting access)</td>
</tr>
<tr>
<td>Illustrative dose to site personnel (siding workers), wagon de-coupling and de-latching</td>
<td>&lt; Design Target (after Remote operations employed)</td>
<td>&lt; Design Target (after Remote operations employed)</td>
<td>&lt; Design Target (after Remote operations employed)</td>
</tr>
<tr>
<td>Illustrative dose to health physicists conducting wagon inspection</td>
<td>&lt; Design Target (if conducted on individual packages in the transfer facility, potential for some remote operations also)</td>
<td>&lt; Design Target (if conducted on individual packages in the transfer facility, potential for some remote operations also)</td>
<td>&lt; Design Target (if conducted on individual packages in the transfer facility, potential for some remote operations also)</td>
</tr>
<tr>
<td>Illustrative dose to site personnel heavy goods vehicle (HGV) loads in trailer park (Trailer park workers)</td>
<td>&lt; Design Target (after restricting access)</td>
<td>&lt; Design Target (after restricting access)</td>
<td>&lt; Design Target (after restricting access)</td>
</tr>
<tr>
<td>Illustrative dose to site personnel de-coupling trailers (Trailer park workers)</td>
<td>&lt; Design Target (as operation times reduced to a minimum especially in close proximity to trailers)</td>
<td>&lt; Design Target (as operation times reduced to a minimum especially in close proximity to trailers)</td>
<td>&lt; Design Target (as operation times reduced to a minimum especially in close proximity to trailers)</td>
</tr>
<tr>
<td>Illustrative dose to health physicists conducting trailer inspection</td>
<td>&lt; Design Target (if conducted on individual packages in the transfer facility, potential for some remote operations also)</td>
<td>&lt; Design Target (if conducted on individual packages in the transfer facility, potential for some remote operations also)</td>
<td>&lt; Design Target (if conducted on individual packages in the transfer facility, potential for some remote operations also)</td>
</tr>
</tbody>
</table>
7.1 Discussion of illustrative doses at surface facilities

It can be seen in Table 27 that the predicted doses at surface facilities are independent of the design of a GDF. The scoping calculations (Table 9) show that there would be a potential for illustrative doses above the Design Target from seven operations within the surface facility area. However, by implementing the suggested designs and operating assumptions, these doses would be reduced by either eliminating the hazard or reducing exposure. It should also be noted that illustrative dose rates in surface areas are calculated using bounding estimates of package dose rates. Use of Monte-Carlo sampling techniques of waste package design data in order to calculate dose rates would provide a more realistic, yet conservative estimate.
It can be seen that the annual illustrative unmitigated dose rate to operators at the gate receipt area is the largest surface annual illustrative dose rate and is above the Design Target. Mitigation brings this below the design target and dose rates may be reduced further because the level of inspection required at the gate area is not yet known, therefore in practice the exposure time per year may currently be over estimated.

One area of particular concern would be manual coupling/uncoupling operations in the rail sidings and heavy goods vehicle (HGV) trailer park. At the current illustrative dose rate, just ten hours exposure would result in the Design Target being reached. It is therefore recommended that potential doses in the rail sidings should be eliminated by using remote operations and by restricting man access to the sidings when waste packages are present. General access of workers to the sidings and trailer park would not be allowed. If it is necessary to access the sidings, occupancy would be restricted and controlled. Engineered facilities would be required to allow remote uncoupling operations. This design would eliminate the major contributions to the illustrative dose to operators at the sidings, as wagon coupling/uncoupling would not require operators to be present, and transport package inspection activities would not take place in the sidings. There would be a small residual dose to operators in the sidings associated with train movements, maintenance of trackside equipment etc, but at a much lower level than presented in GOSA. The exposure from these remaining activities would need to be appropriately monitored and controlled. Shielding between the sidings and other surface facilities would be considered.

With remote operations for uncoupling, this would mean that all visual inspection would be carried out on individual packages in the transfer facility after covers had been removed. The illustrative dose for this inspection will be less than the dose if inspection were carried out at the rail sidings as there would be only one package present at a time. The illustrative dose incurred for this operation in the transfer facility will be calculated in future issues of this report, once procedures in the transfer facility have been better defined. If the dose is calculated to be significant, further automation and shielding may be applied.

Similarly, general access to the HGV trailer park would be restricted and controlled. The trailer park may require remote operations for some shielded intermediate level waste (SILW) containers but otherwise manual operations would suffice with adequate monitoring of access and exposure of operatives. There is also no requirement for inspection of the trailers or the transport packages in the trailer park, again this could be moved to the transfer facility. Personnel in all surface facilities who could be exposed to radiation from the sidings or the HGV trailer park would be adequately protected. Coupling/uncoupling operation times in the HGV trailer park would be reduced to a minimum. The exposure time when working in close proximity to a trailer would be reviewed and worker exposure would be monitored to ensure that operator dose targets are not exceeded.

Following the mitigation measures discussed, the predicted annual exposure of sidings and trailer park workers is predicted to be less than the 1 millisievert/year (mSv/y) Design Target.

The predicted annual exposure from airborne contamination whilst performing operations on the surface is 0.1 microsievert/year (µSv/y). This estimate does not include the contribution due to the ventilation of natural radon.

7.2 Discussion of Illustrative doses at underground facilities

It can be seen from Table 27 that annual illustrative doses to underground workers are to be completed and have been identified as future work. It is anticipated that the workers at a higher strength rock facility would incur higher illustrative doses than at the other facilities, as larger vaults can be constructed resulting in longer travel times within the vault and larger faces of packages. Also high level waste (HLW)/ spent fuel (SF) are only manually
emplaced in higher strength rock facilities. The illustrative dose to workers involved in the emplacement of SILW/LLW are geology dependant.

The annual illustrative dose calculated to the Drift Locomotive driver, in both the higher strength rock and lower strength sedimentary rock facilities, is approaching the Design Target of 1 millisievert/year (mSv/y). It is suggested that this calculation is revisited when more detailed specifications regarding the construction and operation of the locomotive are available.

The Fault and Hazard Schedule [25] identified one personnel hazard that could occur during transport to the disposal area under normal conditions. This was the drift inspection; doses from hazards during normal operations. This illustrative dose will be calculated in future issues of this report when more detail is available on the maintenance schedule.

The Fault and Hazard Schedule identified five radiological hazards that could occur at the inlet cell during normal operations. These were:

- dose to inlet cell operator from collection of waste packages (e.g. at buffer store)
- operational doses in inlet cell reception area when the operational area becomes contaminated by the cumulative effects of numerous package operations
- dose to maintenance personnel during maintenance of ventilation ductwork
- dose to inlet cell operator during exchange of filters
- dose to maintenance personnel during maintenance activities conducted in active maintenance workshop - high level

Illustrative doses from normal operations in the inlet cell would be below the Design Target. The principal contribution, albeit comparable with the Design Target, would be the exposure of the operator to an external dose from the buffer store area (container transfer line). Design options will be considered to provide added shielding or further separation between the buffer store and areas normally accessed by the operator in the inlet cell. GOSA states it is unlikely that large numbers of packages would accumulate in the buffer store or that workers would remain in the vicinity of this area for long periods. It is expected therefore that doses from these operations would be below the Design Target. However these calculations will be revisited when more information is available. Illustrative doses incurred during maintenance operations will also be assessed in future issues of this report when maintenance schedules are available.

The Fault and Hazard Schedule identified two normal operation radiological hazards that could occur in the SILW/LLW disposal area. These were:

- dose to maintenance operator during maintenance activities including fork lift maintenance at vault access
- dose to emplacement operator due to external dose during SILW/LLW emplacement operations

Based on the calculations performed in this report it was identified that the principal contribution would be the exposure of the operator to external dose from the SILW/LLW Vault. However, the contribution from collecting packages from the buffer store has not yet been calculated. This dose will also be geology dependant as the distance from the buffer store to the emplacement vault would vary, though the predicted illustrative dose in the lower strength sedimentary rock and evaporite facilities are similar. There is potential for significant doses to the stacker truck driver during emplacement of SILW/LLW. However, if necessary, the cab would be designed to provide adequate shielding to enable SILW/LLW emplacement operations to be conducted over the expected occupancy times. Also, training of the stacker truck driver would be provided to keep the occupancy time to a minimum. It is also assumed that these operations would be appropriately managed and
operator doses would be monitored and controlled, to ensure compliance with Design Targets.

The illustrative dose to an operator during HLW/SF disposal tunnel backfill for the higher strength rock geology was also calculated and found to be considerably below the Design Target.

In general all operations within the facility would be managed so that operator doses could be controlled and their compliance with the design criteria demonstrated. More remote operations would also be considered.

Doses to operators from maintenance activities and waste arisings such as washings and effluents cannot be assessed with confidence until further design detail is developed. Application of design principles would ensure that the design of equipment and the operations would minimise arisings, minimise the need for maintenance, and would ensure that maintenance could be done safely.

The Fault and Hazard Schedule identified no operational radiological hazards that could occur in the unshielded intermediate level waste (UILW) disposal area during normal operations, as all of this area is remotely operated.

The Fault and Hazard Schedule identified six normal operation radiological hazards that could occur from the facility-wide systems. These were:

- dose to maintenance operator from normal maintenance of ventilation system equipment
- dose to site personnel operators from radioactive gases generated in underground vault
- dose to operator from external dose from bowser, effluent tanks, etc
- dose to site personnel from external dose through pipework due to normal liquid effluent discharge from inlet cell activities
- external dose from vault contents through grout delivery pipe and borehole
- dose to site personnel from the generation of washings and arisings

Calculations presented in the GOSA show that operations of the Facility wide systems should not result in operator doses that would exceed Design Targets. Doses to operators from washings and arisings are not expected to exceed targets either. This would need to be demonstrated in the detailed design.

The proposed further work, calculated doses and possible improvement identified, suggest that a GDF would meet the Design Targets.

7.3 Discussion of public illustrative doses

The estimated $4 \times 10^{-3} \text{mSv per year}$ illustrative dose due to skyshine contribution is significantly below the $2 \times 10^{-2} \text{mSv per year}$ Design Target for members of the public. It should be noted that the skyshine contribution is more significant than the direct shine dose in this geometry and hence skyshine contribution should be taken into account in any future illustrative dose estimates which are made as the details of the design and operation of the facility develops.
8 Future work

8.1 Surface facilities for which illustrative doses should be calculated

8.1.1 Active effluent treatment plant
Washings from transport containers and from decontamination activities, are expected to be collected and processed in an active effluent treatment plant prior to discharge into the environment. These areas will be revisited in later issues of this report when more information becomes available. This will also include the calculation of illustrative doses to various workers from active effluent bowsers and effluent pipework.

8.1.2 Active laundry and laboratories
An active laundry and laboratory are described in the design reports, but as annual dose rates in these areas are expected to be much lower than in locations where waste packages are present, annual doses to operators in these areas are not assessed at this stage. These areas will be revisited in later issues of this report when more information becomes available.

8.1.3 Transfer facility
Illustrative dose to operators who would now be performing package inspection, will be calculated once procedures within the transfer facility have been defined more clearly.

8.1.4 Inhalation Illustrative dose
The inhalation illustrative dose to workers on the surface currently only accounts for gaseous radionuclides which are discharged from the below ground vaults. It does not include the contribution from natural radon or from discharges from the maintenance facility for reusable transport containers. The rate of emanation of natural radon will be dependant on the local geology. For this reason, the calculation of annual illustrative dose contribution to workers due to the inhalation of radon will be revisited in later issues of this report, when more information becomes available.

8.1.5 Maintenance activities
No maintenance activities are assessed within this issue of the report due to uncertainties in the maintenance schedule. These will be addressed in future issues of this report.

8.2 Underground facilities for which illustrative doses should be calculated

8.2.1 Active effluent
This will involve the calculation of illustrative doses from active effluent bowsers and effluent pipework to various workers.

8.2.2 Inhalation Illustrative dose
The rate of emanation of natural radon will be dependant on the local geology; natural radon will be most prevalent in the higher strength rock scenario. For this reason, the calculation of annual illustrative dose contribution to workers due to the inhalation of this radon will be revisited in later issues of this report when more information becomes available. The radon levels will be fully characterised during site investigation and factored into the ventilation design.
8.2.3 Maintenance activities

No maintenance activities are assessed within this issue of the report due to uncertainties in the maintenance schedule. For this reason inspection of the drift, maintenance of ductwork, exchange of filters, maintenance activities in the active workshop, maintenance of ventilation equipment and also external dose through grout delivery pipe will be addressed in future issues of this report.

8.2.4 SILW/LLW buffer store

The same methodology that was used to calculate illustrative doses to the stacker truck operator emplacing packages within the shielded intermediate level waste (SILW) / low level waste (LLW) vault could be used to calculate illustrative doses to the operator collecting packages from the buffer store for transfer to the vault. This will be considered for future issues of this report.

8.2.5 HLW disposal area

It has been previously mentioned that in the higher strength rock facility the high level waste (HLW) disposal area would not employ remote operations. Therefore a more detailed illustrative dose assessment for these personnel will be performed in later issues of this report.

8.2.6 Areas not containing packages

There are a number of areas that would not contain waste packages or any other specific sources of radiation. However, these areas may become contaminated due to the transit of personnel or packages. The illustrative dose to operators in these areas may require calculation in future issues of this report. It is understood that these areas are:

- UILW Bogie Decontamination Cell
- UILW/SILW/LLW Service Tunnel
- UILW/SILW/LLW Effluent Sampling laboratory, Receipt and Dispatch
- truck and locomotive garages and turning area
- backfill batching area
- workshop
- storage hall
- personnel hall
- battery charging area
- spoil bunker
- rock drainage hall
- mines rescue room
- HLW/UILW/SILW/LLW ventilation hall

8.2.7 Areas using remote operations

A number of areas exist where remote operations would be utilised. In this report no estimate of worker illustrative doses has been calculated for these areas. In future reports it may be necessary to consider the amount of shielding associated with these areas and calculate illustrative doses to workers in the vicinity of these operations. It is understood that these areas include:
• UILW Transfer Tunnel
• UILW Emplacement Vault
• UILW Inlet cell area
• UILW/SILW/LLW Effluent Receipt/Despatch
• HLW Transfer Hall
• HLW Transport Tunnel
• HLW emplacement vault in the Lower Strength sedimentary rock and evaporite geologies.

8.3 Accuracy of doses presented

As many of the illustrative doses calculated in this report are bounding, further modification may be performed in later issues of this report in order to calculate more realistic doses, for example by using Monte-Carlo sampling of packages. Also at this stage there exists some lack of design detail for example in the design of the drift locomotive. It is therefore not appropriate to assign mathematical accuracies to the illustrative doses presented within this issue of this report.

8.4 Operator based illustrative doses

Once a clear working schedule is available regarding the number of shifts and which locations specific operators would work in, illustrative dose assessments for individual operators performing multiple tasks in multiple locations should be determined. This will ensure that individual illustrative doses do not exceed Design Target.
Glossary

**active institutional control**
Control of a disposal site for solid radioactive waste by an authority or institution authorised under RSA 93, involving monitoring, surveillance and remedial work as necessary, as well as control of land use.

**activity**
The number of atoms of a radioactive substance which decay (radioactive decay) by nuclear disintegration each second. The SI unit of activity is the becquerel (Bq).

**Advanced Gas-cooled Reactor (AGR)**
The reactor type used in the UK's second generation nuclear power plants.

**backfill**
A material used to fill voids in a geological disposal facility. Three types of backfill are recognised:
- local backfill, which is emplaced to fill the free space between and around waste packages;
- peripheral backfill, which is emplaced in disposal modules between waste and local backfill, and the near-field rock or access ways; and
- mass backfill, which is the bulk material, used to backfill the excavated volume apart from the disposal areas.

**backfilling**
The refilling of the excavated portions of a disposal facility after emplacement of the waste.

**Baseline Inventory**
An estimate of the higher activity radioactive waste and other materials that could, possibly, come to be regarded as wastes that might need to be managed in the future through geological disposal drawn from the UK Radioactive Waste Inventory.

**becquerel (Bq)**
The standard international unit of radioactivity equal to one radioactive decay per second. Becquerels are abbreviated to Bq. Multiples of Becquerels commonly used to define radioactive waste activity are: kilobecquerels (kBq) equal to 1 thousand Bq; megabecquerels (MBq) equal to 1 million Bq; gigabecquerels (GBq) equal to 1 thousand million Bq.

**bentonite**
A highly sorbing clay material used as a backfill in certain disposal concepts.

**beta activity**
Beta activity takes the form of particles (electrons) emitted during radioactive decay from the nucleus of an atom. Beta particles cause ionisations in biological tissue which may lead to damage. Most beta particles can pass through the skin and penetrate the body, but a few millimetres of light materials, such as aluminium, will generally shield against them.

**buffer**
The buffer is an engineered barrier that protects the waste package and limits migration of radionuclides following waste package failure.
canister
A term used in specific concepts to describe the empty vessel into which a wasteform is placed.

containment
A feature of a geological disposal facility component that contributes to safety. Some engineered barriers provide a significant period of containment of radionuclides by physically confining them to prevent their release into the host geological environment. Other barriers may also contribute to containment by providing sufficient travel time to allow decay of some radionuclides and their daughters to negligible levels.

Committee on Radioactive Waste Management (CoRWM)
CoRWM was set up in 2003 to provide independent advice to Government on the long-term management of the UK’s solid higher activity radioactive waste. In October 2007, CoRWM was reconstituted with revised Terms of Reference and new membership. The Committee will provide independent scrutiny and advice to UK Government and devolved administration Ministers on the long-term radioactive waste management programme, including storage and disposal. Further information available at http://www.corwm.org.uk.

Community Siting Partnership (or Partnership)
A partnership of local community interests that will work with the NDA’s delivery organisation and with other relevant interested parties to ensure questions and concerns of potential Host Communities and its Wider Local Interests are addressed and resolved as far as reasonably practicable and to advise Decision Making Bodies at each stage of the process.

criticality
Criticality is a state in which a quantity of fissile material can maintain a self-sustaining neutron chain reaction. Criticality requires that a sufficiently large quantity of fissile material (a critical mass) be assembled into a geometry that can sustain a chain reaction; unless both of these requirements are met, no chain reaction can take place – the system is said to be sub-critical.

decommissioning
The process whereby a nuclear facility, at the end of its economic life, is taken permanently out of service and its site made available for other purposes.

decommissioning
Removal or reduction of radioactive contamination.

deprecated uranium (DU)
Uranium in which the proportion of U-235 is less than ~0.7%.

deposition hole
Vertical hole within a disposal tunnel in which a HLW, SF, Pu or HEU canister is placed for disposal.

disposal
In the context of solid waste, disposal is the emplacement of waste in a suitable facility without intent to retrieve it at a later date; retrieval may be possible but, if intended, the appropriate term is storage.

disposal canister
A term used to describe the assembly of certain waste types (e.g. HLW, SF, plutonium, HEU) within a metal container, as prepared for disposal.
**disposal facility (for solid radioactive waste)**
An engineered facility for the disposal of solid radioactive wastes.

**disposal tunnel**
Tunnel in which HLW, SF, Pu and HEU canisters are placed for disposal.

**disposal unit**
A waste package, or group of waste packages, which is handled as a single unit for the purposes of transport and/or disposal.

**disposal vault**
Underground opening where ILW or LLW waste packages are emplaced.

**dose, dose rate**
Dose is a measure of exposure to radiation and can be taken to mean effective dose equivalent unless stated otherwise. Similarly, ‘Dose rate’ would mean the effective dose equivalent per unit time. The SI unit of effective dose equivalent is the sievert (Sv), and typical units of dose rate are sievert/hour (Svh⁻¹) and sievert/year (Svy⁻¹).

**drift**
A sloping underground tunnel.

**emplacement (of waste in a disposal facility)**
The placement of a waste package in a designated location for disposal, with no intent to reposition or retrieve it subsequently.

**Environment Agency**
The environmental regulator for England and Wales. The Agency’s role is the enforcement of specified laws and regulations aimed at protecting the environment, in the context of sustainable development, predominantly by authorising and controlling radioactive discharges and waste disposal to air, water (surface water, groundwater) and land. The Environment Agency also regulates nuclear sites under the Environmental Permitting Regulations and issues consents for non-radioactive discharges.

**environmental safety case**
The collection of arguments, provided by the developer or operator of a disposal facility, that seeks to demonstrate that the required standard of environmental safety is achieved.

**evaporite**
The generic term for a geological environment created by the evaporation of water from a salt-bearing solution to form a solid structure.

**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).

**geological disposal**
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.
geological disposal facility (GDF)

An engineered underground facility for the disposal of solid radioactive wastes.

Health and Safety Executive (HSE)

A statutory body whose role is the enforcement of work related health and safety law. HSE is the licensing authority for nuclear installations. The Nuclear Safety Directorate of HSE exercises this delegated authority through the Nuclear Installations Inspectorate (NII) who are responsible for regulating the nuclear, radiological and industrial safety of UK nuclear installations under the Nuclear Installations Act 1965 (as amended) (NIA 65).

higher activity radioactive waste

Generally used to include 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.

higher strength rock

Typically crystalline igneous and metamorphic rocks or geologically older sedimentary rocks where any fluid movement is predominantly through discontinuities.

high enriched uranium (HEU)

Uranium in which the proportion of U-235 is greater than ~20%.

high level waste (HLW)

Radioactive wastes 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.

intermediate level waste (ILW)

Radioactive wastes exceeding the upper activity boundaries for LLW but which do not need heat to be taken into account in the design of storage or disposal facilities.

lower strength rock

Typically geologically ‘young’ sedimentary rocks where any fluid movement is predominantly through the rock matrix.

low level waste (LLW)

LLW is defined as “radioactive waste having a radioactive content not exceeding 4 gigabecquerels per tonne (GBq/te) of alpha or 12 GBq/te of beta/gamma activity”.

managing radioactive waste safely (MRWS)

A phrase covering the whole process of public consultation, work by CoRWM, and subsequent actions by Government, to identify and implement the option, or combination of options, for the long term management of the UK’s higher activity radioactive waste.

Nirex (UK Nirex Ltd)

An organisation previously owned jointly by Defra and the DTI. Its objectives were, in support of Government policy, to develop and advise on safe, environmentally sound and publicly acceptable options for the long-term management of radioactive materials in the United Kingdom. The Government’s response to CoRWM in October 2006 initiated the incorporation of Nirex functions into the NDA, a process which was completed in March 2007.

Nuclear Decommissioning Authority (NDA)

The NDA is the implementing organisation, responsible for planning and delivering the GDF. The NDA was set up on 1 April 2005, under the Energy Act 2004. It is a non-
departmental public body with designated responsibility for managing the liabilities at specific sites. These sites are operated under contract by site licensee companies (initially British Nuclear Group Sellafield Limited, Magnox Electric Limited, Springfields Fuels Limited and UK Atomic Energy Authority). The NDA has a statutory requirement under the Energy Act 2004, to publish and consult on its Strategy and Annual Plans, which have to be agreed by the Secretary of State (currently the Secretary of State for Trade and Industry) and Scottish Ministers.

**Nuclear Installations Inspectorate (NII)**

See HSE

**overpack**

A secondary or additional outer container used for the handling, transport, storage or disposal of waste packages

**period of authorisation**

The period of time while disposals are taking place and any period afterwards while the site is under *Active institutional control*.

**plutonium (Pu)**

A radioactive element occurring in very small quantities in uranium ores but mainly produced artificially, including for use in nuclear fuel, by neutron bombardment of uranium.

**radioactive material**

Material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity.

**radioactive waste**

Any material contaminated by or incorporating radioactivity above certain thresholds defined in legislation, and for which no further use is envisaged, is known as radioactive waste.

**Radioactive Waste Management Directorate (RWMD)**

The NDA Directorate established to design and build an effective delivery organisation to implement a safe, sustainable, publicly acceptable geological disposal programme. It is envisaged that this directorate will become a wholly owned subsidiary company of the NDA. Ultimately, it 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.

**radionuclide**

A radioactive form of an element, for example carbon-14 or caesium-137.

**repository**

A permanent disposal facility for radioactive wastes.

**safety cases**

A ‘safety case’ is the written documentation demonstrating that risks associated with a site, a plant, part of a plant or a plant modification are as low as reasonably practicable and that the relevant standards have been met. Safety cases for licensable activities at nuclear sites are required as license conditions under NIA 65.

**shaft**

A vertical or near-vertical tunnel extending underground from the surface.
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 as low as reasonably practicable (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 (SF)

Used fuel assemblies removed from a nuclear power plant reactor after several years use and treated either as radioactive waste or via reprocessing as a source of further fuel.

stakeholders

In the context of this document, people or organisations, having a particular knowledge of, interest in, or be affected by, radioactive waste, examples being the waste producers and owners, waste regulators, non-Governmental organisations and local communities and authorities.

storage

The emplacement of waste in a suitable facility with the intent to retrieve it at a later date.

stillage

A metal frame designed to hold four 500 litre Drums waste packages so that they can be handled, stacked and transported as a single disposal unit.

transport container

A reusable container into which waste packages are placed for transport, the whole then qualifying as a transport package under the Transport Regulations.

transport package

As defined in the IAEA Transport Regulations: ‘the complete assembly of the radioactive material and its outer packaging, as presented for transport.’

uranium (U)

A heavy, naturally occurring and weakly radioactive element, commercially extracted from uranium ores. By nuclear fission (the nucleus splitting into two or more nuclei and releasing energy) it is used as a fuel in nuclear reactors to generate heat.

Uranium is often categorised by way of the proportion of the radionuclide uranium U-235 it contains (see natural uranium, depleted uranium, low enriched uranium and high enriched uranium)

voluntarism

An approach in which communities “express an interest” in participating in the process that would ultimately provide the site for a geological disposal facility. Initially a community would be expressing an interest in finding out more about what hosting such a facility would involve. In the latter stages there would be more detailed discussion of plans and potential impacts.

waste form

The physical and chemical characteristics of an unconditioned waste.

waste package

The complete assembly of waste container and wasteform as prepared in accordance with requirements for handling, transport, storage and disposal.
Appendix A  Drawings

1. Example surface layout for a GDF

2. Example underground layout for higher strength rock concept example
3. Example underground layout for lower strength sedimentary rock concept example
4. Example underground layout for evaporites concept example
References


12. Her Majesty’s Stationery Office, Ionising Radiations Regulations 1999 (IRR99)


31. AMEC, Routine Dose Assessment for the SILW/LLW Fork-Lift Truck Driver in a geological disposal facility, September 2009.