

Geological Disposal

Generic Operational Safety Assessment

Volume 2 - Normal operations

Safety Assessment

December 2016



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ISBN 978-1-84029-546-7

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Preface

Radioactive Waste Management Limited (RWM) has been established as the delivery organisation responsible for the implementation of a safe, sustainable and publicly acceptable programme for the geological disposal of the higher activity radioactive wastes in the UK. As a pioneer of nuclear technology, the UK has accumulated a legacy of higher activity wastes and material from electricity generation, defence activities and other industrial, medical and research activities. Most of this radioactive waste has already arisen and is being stored on an interim basis at nuclear sites across the UK. More will arise in the future from the continued operation and decommissioning of existing facilities and the operation and subsequent decommissioning of future nuclear power stations.

Geological disposal is the UK Government's policy for higher activity radioactive wastes. The principle of geological disposal is to isolate these wastes deep underground inside a suitable rock formation, to ensure that no harmful quantities of radioactivity will reach the surface environment. To achieve this, the wastes will be placed in an engineered underground facility – a geological disposal facility (GDF). The facility design will be based on a multi-barrier concept where natural and man-made barriers work together to isolate and contain the radioactive wastes.

To identify potentially suitable sites where a GDF could be located, the Government has developed a voluntarist approach, based on working with interested communities that are willing to participate in the siting process. The siting process is on-going and no site has yet been identified for a GDF.

Prior to site identification, RWM is undertaking preparatory studies which consider a number of generic geological host environments and a range of illustrative disposal concepts. As part of this work, RWM maintains a generic Disposal System Safety Case (DSSC). The generic DSSC is an integrated suite of documents which together give confidence that geological disposal can be implemented safely in the UK.

Executive Summary

The principal safety claim (SC) to be demonstrated for the normal operations safety assessment is that:

OSC.SC2: All reasonably practicable steps will have been taken to implement design provisions whose function is to prevent or minimise routine exposures to radiation sources.

At this stage of the geological disposal facility (GDF) programme the focus of the normal operations assessment is on those areas where: design provisions, engineered protection or process design and optimisation will be required. The approach is largely at the level of a proof of feasibility study which is appropriate for the current stage of the GDF design development. A detailed description of a specific site layout, design, operational activities and associated tasks is not yet available for the GDF, nor would it be expected, for this stage of the GDF programme. Hence this illustrative normal operations safety assessment is based on a representation of the GDF as: a functional process flow description (PFD), a high-level description of activities and the required plant & equipment that could be used to implement the required functions. An illustrative normal operations safety assessment, covering operations in the GDF, has been performed for both operators and members of the public. The standard mechanisms by which the GDF operators, other on-site workers and members of the public could receive a radiological dose as a result of normal operations are:

- external radiation in the form of a direct dose
- internal radiation such as inhalation of particulate material or gaseous discharges as a result of activities on the site

The Radioactive Waste Management Limited (RWM) Nuclear Operational Safety Manual (NOSM) specifies the methodologies and approaches to be adopted for the calculation of normal operations doses, to both operators and members of the public, in accordance with current nuclear industry standards and relevant good practice. However, at the current generic GDF stage, there is insufficient design definition in terms of normal operational activity to be able to perform a full safety assessment. As a result, the assessment is illustrative and a demonstration of feasibility. In identifying those areas of the GDF and the worker groups that are considered the most significant in terms of doses, this assessment prioritises those areas and activities that need to be managed, reduced and optimised through appropriate design provisions. This means that any calculated doses are used simply to signpost the assessment in terms of distinguishing the high potential hazard areas. This provides the focus for the development of suitable design solutions to ensure that RWM safety criteria will be met.

The dose rates which are used in the initial assessment to confirm correlation with the PFD are the fully unmitigated illustrative values. These dose rates, calculated in the absence of GDF safety measures, are therefore a measure of the maximum harm potential. The unmitigated values do not represent the likely dose rates that would arise in a real GDF which will include sufficient safety measures in the design.

The future assessment of the radiological risks arising from normal operations will require the calculation of radiological doses post-mitigation ie with the inclusion of safety measures claimed in a full safety assessment. For the normal operations safety assessment the calculation of the doses received by GDF operators will include all passive safety measures and safety functions included in the design. At the current generic stage, the plant and task design is not expected to be sufficiently detailed to allow such analysis to be performed and as such conclusions can only be drawn consistent with the nature of the assessment. This precludes any definitive statement in relation to acceptability of mitigated doses. However what can be stated are the specific performance requirements, in terms of dose-rate targets

that will need to be met by optimising time, distance and shielding. Illustrative assessments have been undertaken for:

- bounding throughput years for waste streams
- the receipt and handling of high heat and low heat generating wastes
- the different worker groups that undertake specific tasks

The assessment is on the basis of the following assumptions:

- Operator doses under normal operating conditions will be dominated by external direct radiation exposures for which the surface dose rates from waste packages are known and well understood. Compliance with the limits and conditions in the IAEA Regulations for the Safe Transport of Radioactive Material (the Transport Regulations) supports this assumption on the nature of waste packages.
- Operator doses from the inhalation pathway have not been calculated as:
 - Transport packages have strict limits on removable contamination levels on their surfaces in order to comply with the IAEA Regulations for the Safe Transport of Radioactive Material (the Transport Regulations) as limited by the waste package specification and the appropriate release rates in accordance with the A_2 values (whichever is the most onerous). The design intent is that the GDF will be operated as a 'clean' facility, thus at this stage the risk of a dose through an inhalation pathway is judged to be negligible.
 - Air change rates arising from the ventilation systems will be higher than required by codes and standards for nuclear facilities due to the requirement to retain a workable environment underground for GDF operators. This further reduces the potential airborne contamination levels associated with any minor entrained contamination.
 - The gaseous radioactive release from packages is assumed to be negligible when compared with the external dose contributor.
 - Natural radon gas has not been assessed at this stage as the emanation rate will be highly dependent on the precise nature of the host rock and equilibrium air concentration and upon the local air change rate provided by the underground facility extract ventilation system which will be assessed at the site-specific stage¹.
 - Ingestion and injection pathways - doses to operators and other on-site workers are considered to arise during fault conditions and are therefore not assessed within the NOSA.
- Doses to members of the public have been calculated only from aerial discharges based on RWM generic data on the behaviour of waste packages and the waste form under emplacement conditions. As such:
 - The contribution from external radiation, including skyshine from back scatter of neutron sources, has not been assessed as the provision of shielding in the transport package will limit offsite dose potential to levels that will be managed through refinement of the site layout. This shielding is required to meet the requirements of Transport Regulations and will remain in place during all surface handling operations.

¹ The management of natural radon gas is subject to specific legislative requirements for the protection of personnel and is known to be manageable through the provision of suitable underground facility extract ventilation systems, which will be designed specifically for the GDF.

- Further work is required to ascertain the off-site dose rate from transport packages located on the surface, for example, in the buffer storage park².
- Doses from authorised liquid discharge points will be calculated when there is an appropriate level of detail of the composition of effluents (post-treatment), design of the effluent handling systems, and information on the potential sites such as topography. These are not expected to be significant due to the nature of operations undertaken at a GDF.
- Doses to operators and other on-site workers from ingestion and injection pathways are considered to arise only during fault conditions and are therefore not assessed within the normal operations dose assessment.

The normal operations safety assessment should, in principle, provide an assessment of both normal operations and anticipated operational occurrences to fully satisfy the NOSM. An anticipated operational occurrence is an operational process deviating from normal operation which is expected to occur at least once during the operating lifetime of the facility but which, in view of appropriate design provisions, does not cause any significant damage to items important to safety or lead to accident conditions. However, at the current illustrative stage, this assessment is limited to consideration of normal operations only. Additional details would be required, on specific operations and plant design, to assess anticipated operational occurrences.

Illustrative operator dose assessment

The dose assessment for GDF operators has been limited, at this generic stage of the Operational Safety Case (OSC), to an assessment which is illustrative and is based on the tasks identified from the PFD. The general processes required in the GDF have been grouped to aid understanding and assessment of activities. This gives a reasonable understanding of the aggregate dose burden and a means of identifying issues which may be sensitive to assumptions of this nature. The assessment has been performed where there is the likelihood of direct exposure to radioactive sources or to elevated dose rates in the absence of design provisions.

Detailed assessments have been carried out for a combination of waste streams in waste package types for a throughput defined by the transport schedule in the 2013 Derived Inventory report. Process-specific dose calculations for these general operations have been undertaken based on bounding throughput years for the receipt and handling of high and low heat generating wastes. A set of aggregated task times and distances, with generic assumptions related to which group undertakes the tasks, have been used for calculations at this generic stage.

These illustrative assessments provide the basis to develop understanding and to inform future GDF design development. This supports all future optioneering, for which system requirements will need to be derived and robust engineering solutions developed.

The illustrative assessment comprises the following steps:

- Association of the tasks in the PFD with operations and assumptions (time, distance etc.) to describe the task input to the assessment.
- Application of the transport and operational dose assessment (TODA) toolkit, which is a model developed by RWM to enable calculation of the dose from the illustrative tasks and allocation to worker groups supporting the process as defined above in the PFD.

² It is assumed that the design and operating philosophy will be sufficient to ensure that the contribution of external radiation is insignificant.

- Review of the output from the assessment and the 'effort profile' in order to confirm that it is consistent with the PFD before interpretation of the results. This ensures that the data used in the assessment are correctly associated to the activities that they relate to in the PFD, and that the output is used and clearly linked to design requirements.
- Where the fully unmitigated illustrative assessment shows that the doses for a man year of effort require reduction:
 - Calculation of the attenuation (dose reduction) factor required for the activity/area where design optimisation can be applied.
 - Confirmation that it is technically feasible for the illustrative solution to achieve the specified dose reduction factors based on the consideration of time, distance and shielding provisions.
 - Support for the claims made by reference to nuclear facilities currently in operation which have similar dose reduction factor requirements to the GDF, to further demonstrate feasibility.

It should be noted that the results from this illustrative assessment are closely linked to the baseline assumptions within the Basis of Operational Assessment (BOA) report. Results should be interpreted in the context of the BOA assumptions regarding time, distance and the presence of workers during operations. Additional findings from this illustrative normal operations safety assessment are as follows:

- The identification of 'pinch points' (ie where collective hours allocated to an exposed group exceeds the maximum hours available in a year), and relationship to process viability confirms the need to focus on and refine the data in a 'time and motion' type study. This will be an integral part of future design work. This will ensure a robust basis for the design, assumptions and the full safety assessment.
- The remote handling areas of the GDF (ie those areas with a high radiological dose-rate or cumulative dose which currently include the sub-surface inlet cell) have been identified and confirmed as consistent with the PFD.

Mitigated normal operations dose rates have not been calculated at this stage as it is not meaningful or appropriate to do so.

Illustrative public dose assessment

The Operational Environmental Safety Assessment includes illustrative calculations of the annual doses to a member of the public from aerial discharges. The total dose to members of the public from peak gas releases during the operational period is predicted to be significantly below the legal limit for members of the public. This is based on the reference case, with conservative assumptions appropriate to this generic stage. As a result, design optimisation will be undertaken in accordance with the RWM integrated design and safety process. Any actual radiological dose from off-site discharges from the GDF will be determined by site-specific factors and will be a function of actual gaseous discharge rates during each year of GDF operation in combination with local environmental factors and the location and habits of exposed groups. As part of the development of the detailed design, safety measures could be introduced to reduce the potential for gaseous discharges from the GDF. This would further reduce the risk of any off-site doses to a member of the public.

Concluding remarks

The extent to which the principal safety claim (OSC.SC2) has been demonstrated is summarised below.

The illustrative normal operations safety assessment presents evidence related to the process that has been followed, the scope of the assessment, nature of hazards identified requiring design provisions, regulatory expectation related to their control, and hazard management strategies that will need to be adopted to prevent or minimise the routine dose exposure.

The illustrative normal operations safety assessment concludes that there is very high confidence that it is feasible that the GDF can be designed and operated safely with radiological exposures and doses to the workforce and members of the general public which will be tolerable and as low as reasonably practicable (ALARP). In addition, the specific findings are as follows:

- RWM has developed a significant capability for assessing doses based on a functional PFD of the GDF. This allows the contribution to the overall normal operational dose burden by waste stream, package, location and schedule to be rapidly and clearly assessed with confidence. This capability enables an assessment of the viability of the GDF process based on man-effort requirements and identification of any 'pinch points'. This represents a significant improvement in capability since the 2010 generic DSSC.
- Process areas, and their associated operations and locations, requiring engineered provisions have been identified. For example, where unshielded Intermediate Level Waste is to be handled, provisions such as shielded remote handling facilities or 'hot cells' will be implemented (within the current illustrative concept, this facility is provided by the inlet cell).
- RWM now has the capability to identify those areas of the GDF where future effort needs to be focussed on:
 - optimising the design, and
 - increasing the understanding related to process needs such as definition of detailed tasks performed by the operators
- The required dose reduction factors can be achieved through standard nuclear industry solutions. Proposed solutions will be derived through optioneering and appropriate task-design to ensure doses from normal operations in the GDF will be demonstrably ALARP.
- Annual doses to a member of the public from aerial discharges, based on peak gas releases during the operational period, are predicted to be acceptable and significantly below the legal limit.

It should be noted that this safety assessment identifies illustrative safety measures to meet the dose reduction targets. It does not conclude that those measures are the correct solution as this assessment has not yet been supported by suitable optioneering, including application of the 'eliminate, prevent, protect and mitigate' hierarchy. Neither is it assumed that legal requirements have been met in full at this generic stage.

In broad terms the processes and operations conducted at a GDF are functionally the same, or very similar, to those undertaken at numerous High Activity Waste (HAW) Storage and Handling Facilities in operation in the UK. Safety cases and ALARP arguments for the operation of such existing facilities are mature, the engineered systems required to reduce risks are well understood and as such future work will be focussed on implementing a proven solution within an engineered underground facility. This current UK experience, along with international GDF experience, gives high confidence that a suitable design solution can be developed such that the GDF can be operated safely. The design will need to consider the specific requirements of operating a nuclear facility in the sub-surface environment, which may present certain challenges which are relatively unique but are not expected to require novel technological solutions. The areas which require further work to fully underpin the

principle claim are largely related to actual design development and the resolution of the forward action plans.

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1 Introduction

1.1 The generic Disposal System Safety Case

RWM has been established as the delivery organisation responsible for the implementation of a safe, sustainable and publicly acceptable programme for geological disposal of the UK's higher activity radioactive waste. Information on the UK Government and devolved administrations³ approach to implementing geological disposal, and RWM's role in the process, is included in an overview of the generic Disposal System Safety Case (the Overview) [1].

A geological disposal facility (GDF) will be a highly-engineered facility, located deep underground, where the waste will be isolated within a multi-barrier system of engineered and natural barriers designed to prevent the release of harmful quantities of radioactivity and non-radioactive contaminants to the surface environment. To identify potentially suitable sites where a GDF could be located, the Government is developing a voluntarism approach based on working with interested communities that are willing to participate in the siting process [2].

Development of the siting process is ongoing and no site has yet been identified for a GDF.

In order to progress the programme for geological disposal while potential disposal sites are being sought, RWM has developed illustrative disposal concepts for three types of host rock. These host rocks are typical of those being considered in other countries, and have been chosen because they represent the range that may need to be addressed when developing a GDF in the UK. The host rocks considered are:

- higher strength rock , for example, granite
- lower strength sedimentary rock, for example, clay
- evaporite rock, for example, halite

The inventory for disposal in the GDF is defined in the Government White Paper on implementing geological disposal [2]. The inventory includes the higher activity radioactive wastes and nuclear materials that could, potentially, be declared as wastes in the future. For the purposes of developing disposal concepts, these wastes have been grouped as follows:

- High heat generating wastes (HHGW): that is, spent fuel from existing and future power stations and High Level Waste (HLW) from spent fuel reprocessing. High fissile activity wastes, that is, plutonium (Pu) and highly enriched uranium (HEU), are also included in this group. These have similar disposal requirements, even though they don't generate significant amounts of heat.
- Low heat generating wastes (LHGW): that is, Intermediate Level Waste (ILW) arising from the operation and decommissioning of reactors and other nuclear facilities, together with a small amount of Low Level Waste (LLW) unsuitable for near surface disposal, and stocks of depleted, natural and low-enriched uranium (DNLEU).

RWM has developed six illustrative disposal concepts, comprising separate concepts for HHGW and LHGW for each of the three host rock types. Designs and safety assessments for the GDF are based on these illustrative disposal concepts.

³ Hereafter, references to Government mean the UK Government including the devolved administrations of Wales and Northern Ireland. Scottish Government policy is that the long term management of higher activity radioactive waste should be in near-surface facilities and that these should be located as near as possible to the site where the waste is produced.

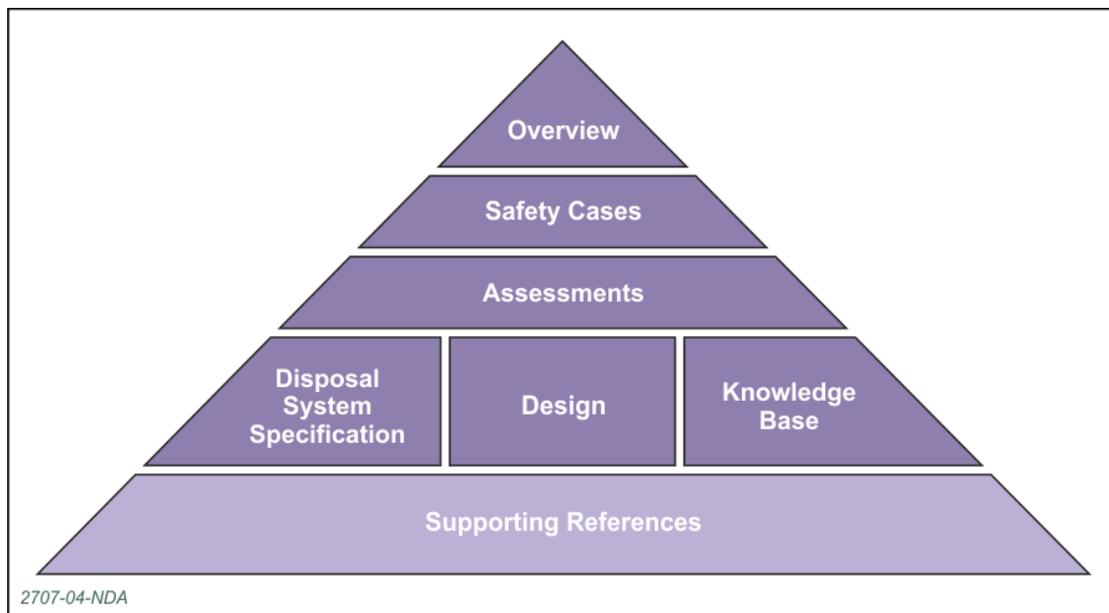
High-level information on the inventory for disposal, the illustrative disposal concepts and other aspects of the disposal system is collated in a technical background document (the Technical Background) [3] that supports this generic Disposal System Safety Case.

The generic Disposal System Safety Case (DSSC) plays a key role in the iterative development of a geological disposal system. This iterative development process starts with the identification of the requirements for the disposal system, from which a disposal system specification is developed. Designs, based on the illustrative disposal concepts, are developed to meet these requirements, which are then assessed for safety and environmental impacts. An ongoing programme of research and development informs these activities. Conclusions from the safety and environmental assessments identify where further research is needed, and these advances in understanding feed back into the disposal system specification and facility designs.

The generic DSSC provides a demonstration that geological disposal can be implemented safely. The generic DSSC also forms a benchmark against which RWM provides advice to waste producers on the packaging of wastes for disposal.

Document types that make up the generic DSSC are shown in Figure 1. The Overview provides a point of entry to the suite of DSSC documents and presents an overview of the safety arguments that support geological disposal. The safety cases present the safety arguments for the transportation of radioactive wastes to the GDF, for the operation of the facility, and for long-term safety following facility closure. The assessments support the safety cases and also address non-radiological, health and socio-economic considerations. The disposal system specification, design and knowledge base provide the basis for these assessments. Underpinning these documents is an extensive set of supporting references. A full list of the documents that make up the generic DSSC, together with details of the flow of information between them, is given in the Overview.

Figure 1 Structure of the generic DSSC



1.2 Introduction to the Operational Safety Assessment: Volume 2 - Normal Operations Safety Assessment

This document is the Normal Operations Safety Assessment (NOSA) and is one of four volumes that, together with a summary report make up the generic Operational Safety Case (OSC). The OSC is part of the generic Disposal System Safety Case (DSSC).

The generic DSSC was previously published in 2010. There are now a number of drivers for updating the safety case as an entire suite of documents, most notably the availability of an updated radioactive waste inventory for disposal.

This document updates and replaces the 2010 Normal Operations Safety Assessment published as part of the 2010 generic DSSC suite.

This generic normal operations safety assessment (Volume 2) for the GDF covers normal operational (radiological) activities. It identifies the GDF operational processes associated with an inherent radiological hazard, and any failure of systems (associated with managing the normal operational exposures) that could result in accident-based exposures. Therefore there is a key interface with the Accident Safety Assessment (Volume 3) [4].

1.3 Objective

The principal safety claim (SC) to be demonstrated for the normal operations safety assessment is that:

OSC.SC2: All reasonably practicable steps will have been taken to implement design provisions whose function is to prevent or minimise routine exposures to radiation sources.

This requires consideration of the normal operational radiological doses that could be received by operators and members of the public during the operation of the GDF. The normal operational dose assessment has been limited at this generic OSC stage to an illustrative screening dose assessment with the objective of:

- identifying the normal operations safety requirements, in the form of conceptual safety functions, for which design solutions will be required
- demonstrating that 'needs' can be met and the means of satisfying the 'need' through illustrative concepts
- identifying areas where an improved understanding of the needs is likely to resolve issues raised by the assessment
- identifying those areas where the assessment is sensitive to the assumptions made

The detailed methodology and results in this volume are reported in the underpinning assessments which include:

- the hazard assessment document (HAZDOC) Section I: Normal (Radiological) Operations [5]
- the Basis of Operational Assessment (BOA) [6] includes the details of the scope, boundaries and limitations of the generic OSC

This volume provides a summary of the approach and the main conclusions, in order to identify where further work may be required at the next stage in the GDF development programme. Forward action plans (FAPs) are used to capture future work items.

1.4 Scope

The scope of this report covers the following activities:

- all packages arriving at the GDF in transport configuration and their subsequent receipt, handling and emplacement operations up to emplacement, as defined within the BOA report
- assessment of radiological aspects only due to the effects of direct radiation (operators) and controlled releases to the environment (public)
- assessment of the dose uptake predicted in the two most demanding years of operation for each waste group, namely 2044 (LHGW) and 2133 (mainly HHGW). These peak years are determined from the 2013 Derived Inventory report [7] and the associated transport schedule.

The scope of the illustrative normal operations dose assessments has been based on the annual throughput of waste packages using the two most demanding years. As a result, a requirement for further assessment has been identified to consider a 'typical year' of operation as part of FAP.2016.VOL2.01.

Internal radiation exposures to operators and other on-site workers have not been calculated for the inhalation and ingestion and injection pathways (Section 2.2.1).

Annual doses to members of the public from aerial discharges have been calculated (Section 3.7). However the very low level of direct external radiation to the public is not assessed as the layout of buildings and facilities at the surface is not currently defined and the distances to the nearest point of habitation are not known at the generic stage. Doses from authorised liquid discharge points will only be calculated when there is an appropriate level of detail of the composition of effluents (post-treatment), design of the effluent handling systems, and information on the candidate sites such as topography.

The NOSA provides an assessment of normal operations in accordance with the requirements of the RWM Nuclear Operational Safety Manual (NOSM) [8]. However, at the current generic stage of GDF implementation, there is insufficient design definition in terms of the normal operations activities to be able to perform a definitive safety assessment including any anticipated operational occurrences.

The level of assessment is considered to be appropriate to the generic stage and is underpinned by a functional PFD which represents the principal activities to be performed in the GDF. There is also a consideration of typical operator groups based on the nature and allocations of tasks. In combination this enables the normal operations safety assessment to present an illustrative, robust and systematic analysis, with a clear derivation of feasibility issues to be considered in accordance with the objectives stated in Section 1.3.

The dose rates which are used in the initial assessment to confirm correlation with the PFD are the fully unmitigated illustrative values (ie calculated in the absence of GDF safety measures and therefore a relative measure of the maximum harm potential).

The full (future) assessment of the radiological risks arising from normal operations will require the calculation of radiological doses post mitigation ie with the inclusion of all safety measures claimed in the safety assessment. For the normal operations safety assessment, this will comprise the calculation of the doses received by GDF operators with all passive safety measures in the illustrative design delivering their required safety functions. At the current generic stage, the plant and task design is not sufficiently detailed to enable a full assessment to be completed. Conclusions can only be drawn consistent with the nature of this assessment. Therefore a definitive statement in relation to acceptability of mitigated doses is not made at this stage. Assessment of mitigated doses will be undertaken in future when a sufficiently detailed design is available. However, what can be stated at this stage are the specific performance requirements in terms of dose-rate targets that will need to be met by optimisation of time, distance and shielding.

This report does not cover environmental impacts (with the exception of normal operational planned discharges), nor does it cover the transportation of waste packages to the GDF until

they pass the licensed site boundary. These aspects are covered in the Environmental Safety Case (ESC) [9] and Transport Safety Case (TSC) [10].

1.5 Document structure

This report is structured in the following sections:

- Section 2 presents: the safety criteria (eg the legal dose limits) against which the screening dose assessment is compared, the key principles of radiological protection and the methodology applied to calculate the screening doses and limitations. It also includes a brief description of the transport and operational dose assessment (TODA) toolkit and the work undertaken post-TODA analysis
- Section 3 presents: the results of the assessment, how the assessment has been used to develop an understanding of the process needs, the output of the illustrative operator and public dose assessments and the approach that will be applied to the development of the GDF design (with regard to normal operations radiological hazards)
- Section 4 describes the future work for normal operations dose assessment that is needed to address issues raised by this document
- Section 5 summarises the assessments undertaken, the results and conclusions with respect to the operational safety case of the GDF

Common terms and acronyms used throughout the generic DSSC are defined in the glossary and acronym list in the Technical Background document.

2 Safety Assessment Methodology

The normal operations safety assessment aims to identify potential areas of concern in terms of radiological hazards within the GDF, along with potential measures to resolve the concerns. The aim of the assessment is to demonstrate the feasibility of meeting the safety requirement and to present arguments and evidence to satisfy the following subsidiary claims:

- RWM has developed a significant capability for assessing normal operational doses based on a PFD of the GDF
- the viability of the process based on man-effort requirements can be demonstrated and any 'pinch points' can be readily identified
- the required dose reduction factors can be achieved through standard nuclear industry solutions and any proposed solution will be derived through optioneering and appropriate task-design to ensure doses from normal operations in the GDF will be demonstrably ALARP
- there is very high confidence that it is feasible to design a GDF so that it can be operated safely, with any radiological exposures and doses to the workforce and members of the general public minimised and shown to be tolerable and ALARP

2.1 Safety criteria

The normal operations safety assessment performed for the generic stage of the GDF is based on a screening dose assessment. As part of the feasibility assessment, doses have been compared against the legal whole body dose limits, as reflected in the RWM dose criteria and set out in Table 1 [11]. The illustrative assessment identifies where design provisions and their associated performance requirements (eg engineered or task design) will be required to limit potential exposures and satisfy dose criteria.

Table 1 Normal Operations Radiological Whole Body Dose Criteria

Criterion	Effective Dose Per Calendar Year (mSv)	
	Employees Working with Ionising Radiation	Members of the Public
Legal dose limit/RWM dose limit (criteria)	20	1

The RWM dose limit for other employees on the site is 2 mSv per calendar year. This is not applied in this screening dose assessment because there is insufficient design definition and understanding of the full range of operator activities to be able to perform a meaningful assessment. However it is judged that meeting this target for non-classified workers will not be a driver for the GDF design.

2.2 Methodology

2.2.1 Background

This section of the report presents an overview of the method which has been used to calculate the illustrative screening doses for comparison against targets. It includes:

- the basis from which attenuation factors would need to be derived

- identification of potential design solutions in accordance with the principle of 'eliminate, prevent, protect and mitigate' (as set out in the NOSM) in order to guide the optioneering process
- identification of the current illustrative solution in the GDF concept and the indicative performance requirements that will need to be met
- the basis upon which feasibility may be claimed

The key principles of radiological protection (as stated in [12]) that are applied to the developing GDF design, and will be used in the context of design optimisation, are:

- 'design development and optimisation for radiological protection such as the likelihood of incurring exposure, the number of people exposed and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors'
- 'application of dose limits such that the total dose to any individual from regulated sources in planned exposure situations should not exceed the appropriate dose limits'

The screening assessment has been applied to the exposure groups and pathways:

- operator doses from direct (external) radiation (Section 3.3)
- public doses from releases of airborne activity (Section 3.7)

For normal operations, the illustrative assessment has two parts:

- the dose rates which are used in the initial assessment, to confirm correlation with the PFD, are the fully unmitigated illustrative values (ie calculated in the absence of GDF safety measures and therefore a measure of the maximum harm potential)
- the subsequent assessment of the radiological risks arising from normal operations requires the calculation of radiological doses post mitigation ie with the inclusion of safety measures claimed in the safety assessment and present in the illustrative design. For example, the inclusion of a shielded inlet cell and remote handling emplacement (as an illustrative solution within the GDF concept for unshielded ILW) enables the contribution from these activities to be screened out of the assessment

For the GDF operators and on-site workers, operator doses under normal operating conditions will be dominated by external direct radiation exposures received from disposal units (waste packages).

Internal radiation exposures to operators and other on-site workers have not been calculated at this stage of the design for the inhalation pathway:

- The level of contamination to be expected on packages arriving at the GDF is limited by prescriptive regulation (IAEA Regulations for the Safe Transport of Radioactive Material [the Transport Regulations]) to allow transport in the public domain. The risk to workers at the GDF will be extremely low as a result. This is supported by the design intent that the GDF will be operated as a 'clean' facility with all necessary controls as required by IRR99 to ensure that risks to workers are ALARP from normal operations.
- Air change rates arising from the ventilation systems will be higher than required by codes and standards for nuclear facilities due to the requirement to retain a workable environment underground for GDF operators. This further reduces the potential for airborne contamination levels associated with any minor entrained contamination.
- The gaseous radioactive release from packages is assumed to be negligible when compared with the external dose contributor.

- Natural radon gas has not been assessed at this stage as the emanation rate will be highly dependent on the precise nature of the host rock and equilibrium air concentration. It will be controlled by the local air change rate provided by the underground facility extract ventilation system, the details of which will not be finalised until the site-specific stage⁴.
- Ingestion and injection pathways - doses to operators and other on-site workers arise during fault conditions and are therefore not assessed within the normal operations safety assessment.

Doses to members of the public have been calculated only from aerial discharges based on RWM generic data on the behaviour of waste packages and the wasteform under emplacement conditions. As such:

- The contribution from external radiation, including skyshine from back scatter of neutron sources, has not been assessed as the provision of shielding in the transport package will limit offsite dose potential to levels that will be managed through refinement of the site layout. This shielding is required to meet the requirements of Transport Regulations and will remain in place during all surface handling operations.
- Further work is required to ascertain the off-site dose rate from transport packages located on the surface, for example, in the buffer storage park⁵.
- Doses from authorised liquid discharge points will be calculated when there is an appropriate level of detail of the composition of effluents (post-treatment), design of the effluent handling systems, and information on the potential sites such as topography. These are not expected to be significant due to the nature of operations undertaken at a GDF.

This illustrative assessment has been used to identify the most significant radiological hazard potential locations within the GDF where exposures to direct radiation will require management. Calculated doses are used in order to signpost the assessment in terms of distinguishing the highest potential hazard areas which will provide the focus for the development of suitable design solutions to ensure that RWM dose criteria will be met. Dependent on the magnitude of potential exposure, suitable solutions will range from robust engineered features to administrative controls. This ensures that the needs of normal operations and additional controls identified to prevent faults are correlated in the design requirements. The loss of function of these systems or other errors is the subject of the accident safety assessment.

This normal operational safety assessment has been undertaken for the bounding years for the representative waste streams including the receipt and handling of high & low heat generating wastes. These 'unmitigated' doses provide a measure of the maximum harm potential and are used to identify the key challenges and where design effort should be concentrated. These unmitigated doses are illustrative only and are not representative predictions of expected outcomes in a real GDF ie fully mitigated annual doses.

An initial screening calculation of the potential impact of airborne contamination within the GDF has been performed as part of the feasibility study (Section 3.6). A FAP has been raised related to the need to identify areas which require zoning, designation and/or segregation based on radiological hazard potential. This will ensure designs will be

⁴ The management of natural radon gas is subject to specific legislative requirements for the protection of personnel and is known to be manageable through the provision of suitable underground facility extract ventilation systems, which will be designed specifically for the GDF.

⁵ The design will ensure that the operating philosophy and distances to the nearest point of habitation are sufficient to ensure that the contribution of external radiation is insignificant.

developed to meet the requirements of the Ionising Radiations Regulations 1999 for area designation, control, segregation and clearance procedures (FAP.2016.VOL2.02).

Assessment of dose requires consideration of the contribution from gamma, neutron and Bremsstrahlung radiation. Dose rates from transport packages used as input to the assessment include the contribution from all these sources, and are therefore accounted for in the assessment.

For direct radiation exposure to the public, there are several surface locations in the GDF where numbers of loaded transport packages will be temporarily stored prior to emplacement. These locations include rail sidings, the lorry trailer park and waste package transfer facilities. These 'background dose' sources are discussed in Section 3.5.

The illustrative assessment considered waste categories which are subsets of the generic waste groups set out in Section 1.1. This approach has been taken because the analysis is waste category specific and hence needs to be structured in this way to align with the PFD. Furthermore, it gives a useful discrimination and structure between the radiological hazards, the wastes and the process combinations. For clarity, the relationship between the waste categories is set out in Table 2.

Table 2 Waste Groups and Categories

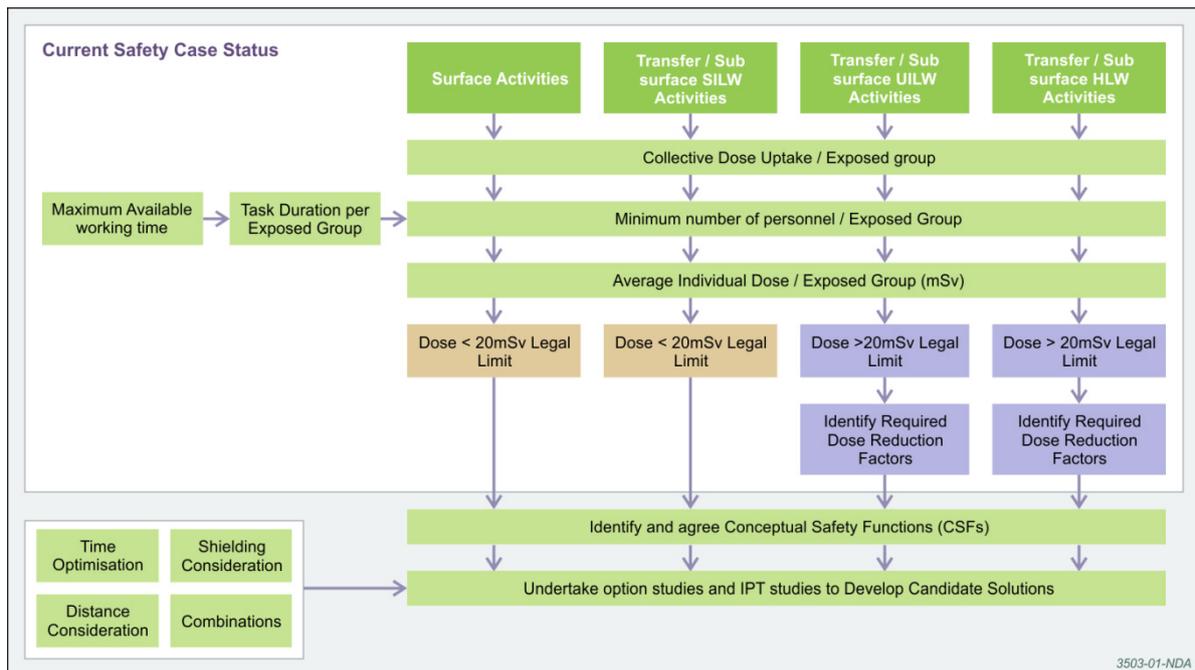
Waste Group	Waste categories
HHGW	Spent fuel, HLW, Pu and HEU component of uranium
LHGW	ILW, LLW and DNLEU component of uranium

2.2.2 Method

The process that has been applied to the illustrative assessment comprises a series of steps, which are detailed below and summarised in Figure 2:

- Step 1 - identification of the tasks to be undertaken by the operators and the operator groups to be considered in the NOSA. This includes separation of surface and sub-surface activities, based on the PFD with associated functional process tasks to describe operations at the GDF. In essence the tasks identify: the manner of arrival, handling and emplacement of the waste packages.
- Step 2 - application of the TODA toolkit in order to calculate the illustrative dose uptake for all required tasks and operator groups.
- Step 3 - review of the output from the screening dose assessment against legal limits/RWM normal operations dose criteria. Where the assessment shows that the screening doses are above the legal limit:
 - calculate the dose reduction factor required to bring the screening dose to the region where design development and optimisation can be applied
 - identify safety functions and conceptual safety functional requirements which will drive the need to define and adopt requirements related to meeting design principles
 - review whether it is feasible to achieve the specified dose reduction factors based on the consideration of time, distance and shielding provisions

This approach is consistent with that applied by other operators in the UK nuclear industry. It focuses on the application of optioneering and optimisation studies in order to develop design solutions that will meet RWM safety criteria and the requirement to ensure that doses are tolerable and ALARP.

Figure 2 Summary of the TODA Output Analysis

Step 1 - Identification of GDF tasks

RWM has developed the PFD to provide the framework from which to assess the operations from receipt to emplacement. It covers all waste package types associated with waste streams in the 2013 Derived Inventory [7]. The PFD, when combined with the task data, provides the structure (for both the input and results) for the dose calculations undertaken using the TODA toolkit (as described in Step 2). The PFD numbering system is common to both the normal operations and accident assessments. This ensures high-hazard areas in the normal operations safety assessment are transparently correlated with areas of concern in the accident safety assessment and will be jointly considered during the design process.

The PFD has been constructed to meet the following requirements:

- start at the point at which a transport package arrives at the GDF receipt facility
- be invariant with time as the GDF concept and future design develops towards the site-specific stage
- include all operations from point of receipt of the transport package to the final underground emplacement of the waste package
- accommodate the addition of new waste package types without restructuring of the PFD
- aid the understanding of the high radiological hazard areas of the GDF and their location
- enable a dialogue with design to ensure the RWM integrated safety and design process is applied

To allow the PFD to be embedded within RWM's GDF design and assessment work, an overarching requirement was that the PFD architecture would have a common interface with the design activities. This ensures that design (engineering) and safety assessment changes are both 'linked' and controlled together. This philosophy is being carried forward into all toolkits supporting the development of the generic OSC. Thus all the steps in the emplacement process, from receipt of waste package at the GDF to final emplacement, are

grouped hierarchically and linked to nodes selected to facilitate the interface with design requirements. The nodes provide the high-level breakdown of the overall waste emplacement process. The PFD has been constructed with individual nodes for different areas of the GDF; the nodes are top-level points (notional facilities) representing a high-level breakdown of the waste emplacement process. Within the PFD there is greater detail at sub-levels covering: modes, processes and tasks. The nodes are:

- N1. Surface receipt and on-site transfer
- N2. Unloading of package from transport vehicle
- N3. Surface preparation of package for below ground transfer
- N4. Underground transfer of package to sub-surface receipt facilities
- N5. Underground preparation of package for emplacement
- N6. Emplacement of package

The details of specific process tasks, from receipt of a waste package to final emplacement, are not meaningful at this stage of GDF concept development without underpinning task and process data. However the general processes expected can be grouped to aid understanding and assessment of activities. This gives a reasonable understanding of the aggregate dose burden and a means of identifying issues which may be sensitive to assumptions. Within each node, individual tasks may be derived that address the sequence of operations currently assumed within the PFD. Table 3 shows the generic operation types that help define the nature of tasks undertaken.

Table 3 Operation Types That Define the Nature of Tasks Undertaken

Operation Type	Operation Type Description
Moving	Transporting waste using vehicles (road/rail), including positioning, parking and opening/closing doors
Lifting	Any tasks involving fixed (not mobile) lifting equipment installed in a facility, including traversing, setting down and winching down a shaft
Unloading	Removing/putting a package on or disengaging/engaging from a vehicle
Unpacking	Changing package configuration
Stacking	Stacking for final emplacement
Monitoring	Checking package identity/compliance
Sentencing	At the onward-transfer end checking a transport package/disposal unit is being sent to the correct disposal area designated for the waste type of the waste package and at the receipt end checking that it has been received in the disposal area, designated for that waste type

At this generic stage, there is no detailed plant and process design description that identifies the operational processes or the operator groups that need to be assessed. In order to allow meaningful interrogation and interpretation of the results from the illustrative dose assessment (related to normal operations), operator groups need to be assumed. Operator groups were assigned to tasks at the process task level as identified by the 'operation type(s)' applicable to the tasks. Without a full operator schedule, it has been assumed that there is just one worker from each applicable group involved in a task. The operator groups assumed are listed in Table 4 below.

Table 4 Notional Operator Groups Required for GDF Tasks

Exposed Person Group	Exposed Person Group Comments
Health physics	Perform acceptance checking on packages, monitoring and plant. Including at every area handover ⁶ .
Task supervisor	Responsible for safety during task and oversees compliance with task operating instructions.
Area supervisor	The duly authorised person oversees certain operations for a nominal amount of time, ensures compliance with RWM procedures, checks paperwork is sufficient, sentences packages and signs off lifts. This may include a DGSA (Dangerous Goods Safety Adviser) signing off transport packages for onward transfer.
Task operative	Performs general checks or handling/unloading tasks
Off-site drivers	Drives vehicles from off-site including rail and road transport into GDF and on to rail sidings/trailer park.
GDF drivers	Drives on site locomotive/cab, drift/shaft and underground vehicles.
Banksman	Supervises and guides movement of package.
Lifting equipment operator	Operates lifting equipment for lifts.

The PFD currently does not include maintenance tasks. However, there are maintenance faults related to the inlet cell, holding cell or emplacement device. These are associated with the point at which a package could be present in the PFD. It is worthy of note that the fault class derived in the Accident Safety Assessment is currently based on an annual maintenance frequency, this may have to change to the same demand as the package process rate if this needs to happen as part of a process requirement.

Step 2 - Application of TODA toolkit

The TODA toolkit was developed by RWM to enable calculation of the normal process related dose burden for associated operator groups. Illustrative comprehensive assessments have been carried out for a combination of waste streams in waste package types, for a given throughput, in combination with the PFD and task data.

The inventory for disposal is specified, in the 2013 Derived Inventory report, as a set of waste streams each with associated waste packaging configurations and the number of units to be transported. For this assessment, the packaging configuration was specified both for packages in their transport configuration as well as their disposal configuration. This is important where the requirement is that wastes are received in a highly shielded configuration but the process assumption is that the disposal unit is removed from the transport container for handling and emplacement (See N6 for Unshielded ILW (UJLW) wastes). This approach ensures that high radiological hazard areas are correctly identified and mapped onto the PFD.

For the purposes of performing screening dose assessments, on the basis of the emplacement schedule assumed in all DSSC assessments, RWM has identified that the

⁶ Node to node in this assessment, but generally facility to facility on an operational site.

most demanding year for LHGW is 2044 and the most demanding year for HHGW is 2133. For these years, the expected number of packages by waste type is presented in Table 5.

Table 5 Expected Number of Packages Processed in Bounding Years 2044 and 2133 by Waste Category

Waste Category	Number of Packages Expected to be Processed	
	Year 2044 (Max. LHGW Year)	Year 2133 (Max. HHGW Year)
LHGW - SILW	640	9
LHGW - UILW	1611	1500
HHGW	0	200
Total	2301	1709

Process-specific dose calculations from these general operations have been undertaken based on a set of aggregated task times and distances. The required specification of TODA input data includes:

- inventory (ie a set of waste streams each with associated waste packaging configurations and the number of units to be transported):
 - for normal operations dose assessments, the packaging configuration needs to be specified both for packages in their transport configuration as well as their disposal configuration
 - certain Shielded ILW (SILW) waste packages qualify as transport packages in their own right and they will be transported and received at the GDF as they are
 - in other cases, disposal units will be transported in re-usable transport containers and will need removal from the transport container prior to final emplacement in the GDF vault; to allow for this complexity, the term ‘transport unit’ is used to refer to the transport package or the transport overpack as appropriate
- reference external package dose rates specified for each waste stream, distance and packaging configuration combination in each year of transportation of that waste stream
- transfer schedule (ie a waste package emplacement schedule⁷)
- waste stream arrival mode set (ie whether transport units arrive at the GDF by road or rail)
- processing policy (ie which disposal mode applies to each waste stream)
- workforce (ie the exposed persons groups and their sizes)
- task set (ie the process flow hierarchy with conditions applied to choose between modes and exposure parameters)
- an attenuation factor to allow for any shielding of the waste package transport unit/disposal unit from the operator if applicable

⁷ For the 2016 generic OSC, this has been assumed to be the same as the transport schedule which specifies how many packages are transported in each year of the transport operation, with the packages identified by their waste stream.

To confirm the validity of the base data, the first pass calculation is performed assuming no design provisions. This ensures that high radiological hazard areas are identified, thereby confirming correct application of the toolkit and providing the base data from which the design provisions can be correctly specified. These results can then be filtered from the full data set to identify the next tier of issues for resolution. This method allows the requirements to be derived and appropriate design solutions to be introduced to remove the dose contribution of that task (eg remote handling for UILW unpacking and emplacement in the illustrative GDF concept [13]).

The TODA output is a structured compilation of the illustrative dose uptakes (as an order of magnitude type of assessment) for each worker group and process, due to the direct radiation from the package. The dose assessment is compliant with the NOSM [8] and forms the basis for comparison against the dose criteria.

Step 3 - Review of the output from the screening dose assessment

In order to calculate the average individual dose, the size of the workforce required to complete the defined set of activities must be determined. This is derived from the total effort (number of man-hours) required to complete the process and the number of process repetitions. The individual effort is limited to the number of hours in a normal working day (ie 8 hours) and the workforce size derived through consideration of the number of individuals required to complete the total work required in a year. Further consideration must also be given to other factors when determining the workforce size as this will be reflected in the individual dose as this is clearly linked to the duration of exposure.

Conversely, this analysis highlights whether the assumptions made result in an assessment that confirms the viability of the proposed waste package throughput. The current GDF design assumption related to throughput and staffing is for 3 shifts working in a 24 hour period, and the predicted doses reflect these assumptions. Any change to this set of assumptions will correspondingly affect the throughput and annual dose burden for instance, the potential for individual exposure to radiation could be limited to 960 hours per year, based on:

- 40 hours in an average working week
- 50% utilisation on radiological tasks and 50% utilisation on non-radiological tasks in accordance with defined task allocation
- 48 weeks per year

Consideration of such issues early in the design process helps identify potential 'pinch points' where there may be a requirement to re-examine:

- the activities undertaken,
- the means of undertaking them (manual versus automation),
- timescales, or
- the number of operators involved

A review was then undertaken against the dose criteria in Table 1 to ascertain the required reduction factors which would enable dose reduction into the range where optimisation can be applied at the appropriate project phase. This information informs identification of the conceptual safety functions, option studies and design interface meetings which are used as part of the RWM design development process.

3 Safety Assessment Results

3.1 Introduction

This section presents the results of the illustrative normal operations safety assessment, and includes:

- an assessment of the viability of the process as detailed in the PFD
- confirmation of correct process assumptions and locations of hazards in the PFD
- identification of areas of the GDF requiring design optimisation
- identification of the processes needing refinement and linking to needs

The results of the assessment are presented in Figures 3 to 6. For each figure:

- the x-axis represents the node/mode combination in the PFD; the sub-division of the nodes reflects the number of different sub-tasks performed in each node
- the y-axis represents either: the process frequency (Figure 3), Ratio of Hazard Potential (Figure 4) or Collective doses (Figures 5 & 6)
- the z-axis represents the GDF worker groups (excluding maintenance staff) as identified in Table 4

3.2 Throughput study

As the GDF is the final disposal system for the UK's HAW inventory, the 'package throughput' is a key design and operational parameter. Understanding what needs to be done to achieve the proposed package throughput is important to determine whether there are specific 'pinch points' which will require further analysis. It is necessary to review whether the collective hours allocated to an exposed group, in order to achieve the desired throughput, exceeds the maximum hours available in a year. The assessment uses the TODA output to identify whether the proposed throughput is viable within the GDF for normal operations in the bounding years of 2044 and 2133 (assuming a 24/7 working pattern).

Process multiples have been calculated to illustrate 'pinch points'. A 'process multiple' is the ratio of the 'time effort needed' to the 'time available' (ie 24 hours per day, 365 days per year). Clearly, there is a 'pinch point' where a 'process multiple' is calculated as being greater than 1.0. The 'process multiples' are derived assuming a single package receipt and handling requirement which provides a baseline of the least efficient receipt arrangements and associated process demand on the GDF. This necessarily takes no account of efficiencies that could be achieved with process automation, staggered or parallel tasking which could increase the throughput capacity. The normal operational dose estimates should be interpreted in this context. Conversely any reduction in throughput will reduce the annual effort required and the annual dose accrued, but would extend the operational phase.

This normal operations safety assessment (NOSA) enables an understanding of the effort requirements by worker group across each of the PFD nodes. The results are detailed in Table 6 and Table 7.

Table 6 Summary of Process Demand by Worker Group for LHGW (2044)

PFD Area	Required Process Multiple (n)							
	Area Supervisor	Banksmen	GDF Drivers	Health Physics	Lifting Equipment Operator	Off Site Drivers	Task Operative	Task Supervisor
N01M01	0.01	0.13	1.09	0.39	-	2.28	0.18	0.49
N02M01	0.31	1.12	0.85	0.09	0.31	-	0.44	0.27
N03M01	0.00	0.44	0.50	0.09	-	-	0.11	0.18
N04M01	0.00	0.07	0.11	0.01	-	-	0.02	0.06
N05M01	0.04	0.05	0.05	0.01	0.04	-	0.06	0.03
N05M02	0.11	0.14	0.14	0.02	0.11	-	0.16	0.09
N06M01	0.08	0.22	0.15	0.02	0.10	-	0.10	0.02
N06M04	0.80	1.74	1.04	0.18	0.85	-	1.01	0.32
Grand Total	1.35	3.90	3.95	0.82	1.41	2.28	2.08	1.45

Table 7 Summary of Process Demand by Worker Group for HHGW (2133)

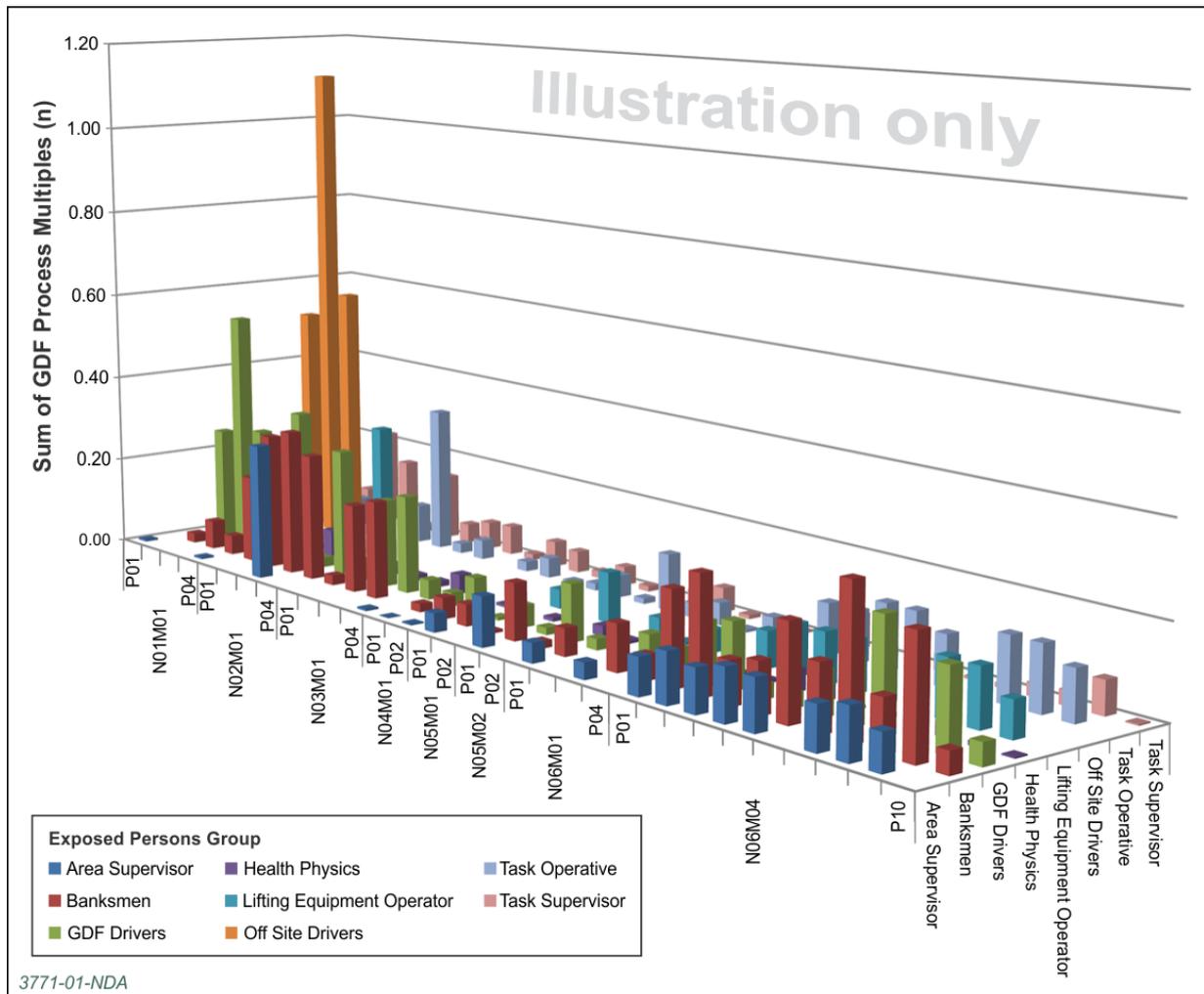
PFD Area	Required Process Multiple (n)							
	Area Supervisor	Banksmen	GDF Drivers	Health Physics	Lifting Equipment Operator	Off Site Drivers	Task Operative	Task Supervisor
N01M01	0.01	0.10	0.85	0.31	-	1.77	0.14	0.38
N02M01	0.24	0.87	0.66	0.07	0.24	-	0.34	0.21
N03M01	0.00	0.34	0.39	0.07	-	-	0.09	0.14
N04M01	0.00	0.05	0.09	0.01	-	-	0.02	0.04
N05M01	0.01	0.01	0.01	0.00	0.01	-	0.01	0.00
N05M02	0.10	0.13	0.13	0.02	0.10	-	0.14	0.08
N05M03	0.01	0.02	0.03	0.00	0.01	-	0.02	0.01
N06M01	0.01	0.03	0.02	0.00	0.01	-	0.01	0.00
N06M04	0.72	1.57	0.90	0.17	0.77	-	0.91	0.29
N06M06	0.04	0.11	0.08	0.01	0.04	-	0.05	0.02
Grand Total	1.14	3.22	3.15	0.66	1.18	1.77	1.73	1.17

For the purpose of illustrating the capability of the assessment method, the results have been presented as a histogram showing:

- the PFD (for the package, receipt, transfer and emplacement process) broken down into nodes and sub-tasks (activities) (x-axis)
- the worker groups undertaking the activities (z-axis)
- the sum of GDF Process Multiples (ie frequency of activity) (y-axis)

Figure 3 shows the output from the illustrative assessment for LHGW for the highest throughput year of 2044 (ie the most demanding operational year).

Figure 3 Illustrative Profile by Effort Requirements (2044)



The vertical y-axis shows the 'process multiple' ie the ratio of total effort required to the maximum number of available working hours in a year. The x-axis shows the operational process step, and the z-axis identifies the worker group responsible for undertaking the activity. This presentation of the analysis (Figure 3) clearly shows the 'pinch points' that will need to be resolved during future design activity. In this case the assessment shows that it is predominantly in the surface operations (Nodes 1 to 3), and with the worker groups of 'drivers' and 'banksmen' that the pinch points occur. This finding is closely linked to the specific assumptions of the task duration and the speed associated with the unloading operations. The ability to systematically assess and expose 'pinch points' is a key capability that will ensure the GDF is optimised in a balanced way. In this case, adopting parallel

processing or a more automated approach could ensure the required throughput is achievable whilst reducing the potential exposure time. All such options will be explored when formal design activity is undertaken.

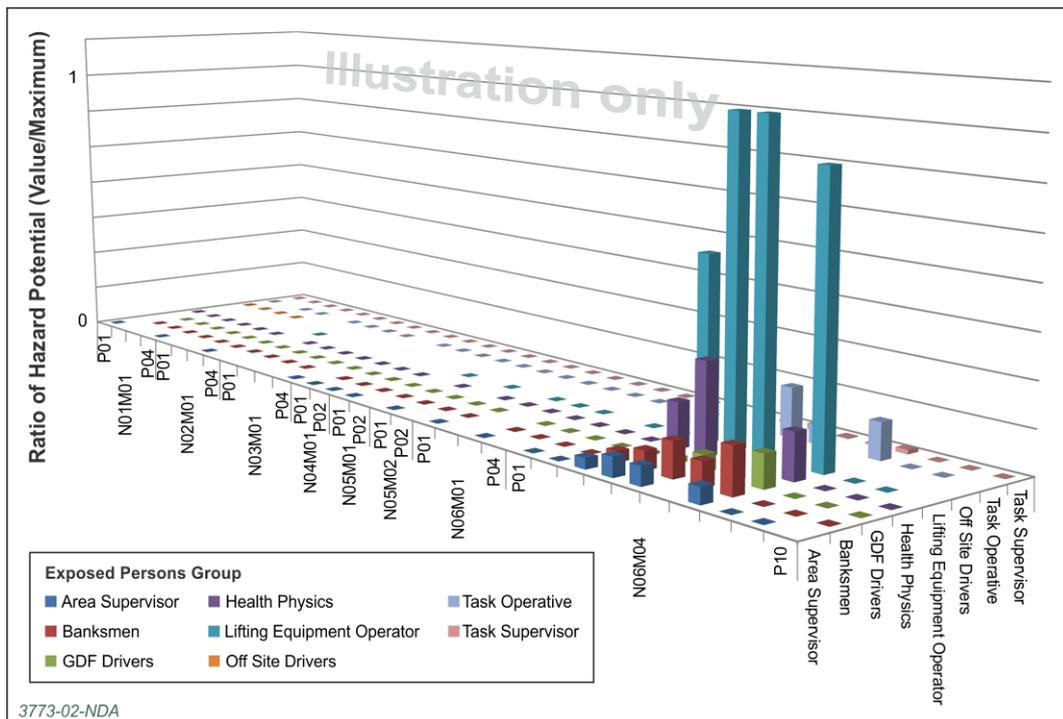
Another conclusion drawn from Figure 3 relates to sub-surface operations (Nodes 5 and 6). The analysis shows that the required throughput is achievable, but also, that the level of effort is significant. This will drive a focus on options that may be available to reduce the duration or magnitude of exposures. Even at the generic stage, the illustrative analysis indicates process task design and optimisation will be required to develop a solution that is demonstrably ALARP.

3.3 Operator screening dose assessment

For the purpose of illustrating the operator screening dose assessment method, the results have been presented as a histogram (Figure 4) showing:

- the PFD (for the package, receipt, transfer and emplacement process) broken down into nodes and sub-tasks (activities) (x-axis)
- the worker groups undertaking the activities (z-axis)
- the ratio of Hazard Potential (Value/Maximum) (y-axis); the vertical axis is a ratio of the hazard potential in a given area for a given operation compared to the maximum hazard potential

Figure 4 Illustrative Process Hazard Mapping (2044)



This shows 'where' the relative hazards exist in the process (PFD) and 'who' (worker group) is potentially most affected by the hazard. This visualisation of the assessment output enables the right focus for more detailed interpretation of the results. In the context of the current generic assessment this example shows that a relatively high hazard is generated at the point at which UILW is removed from its transport container (Node 6), and that it is the 'lifting equipment operators' (those carrying out emplacement) who are most at risk. These operators will require engineered protection. This result might seem simple and intuitive;

however the important point is that the result has been generated through a logical and systematic analytical method.

As a result, the current process assumptions and hazard identification lead to the requirement for remote handling of some waste packages. For UILW this is implemented in the generic design as sub-surface inlet cells and remotely operated vaults in the handling and vault concept.

It is expected that the locations identified as the highest hazard areas for normal operations will also feature in the accident safety assessment [4] as they tend to generate high hazard potential in fault scenarios. The correct application of a safety integrated design process will ensure focus on resolving the most significant issues, and identifying appropriate solutions. The capability demonstrated in the assessment of the GDF at the generic stage underpins claims of feasibility.

The normal operations dose assessment is based on consideration of the hazard potential and process feasibility. It requires some level of understanding of the minimum workforce size. The illustrative assessment considers the collective annual dose burden to each potentially exposed worker group (ie the total dose potentially received by a particular worker group whilst undertaking their assigned activities). The individual dose is then determined based on the amount of effort for an individual within that workforce. At this stage a predictive statement on individual dose cannot be made as the workforce size is not defined.

Figure 5 Illustrative Areas of the GDF Requiring Design Development (2044)

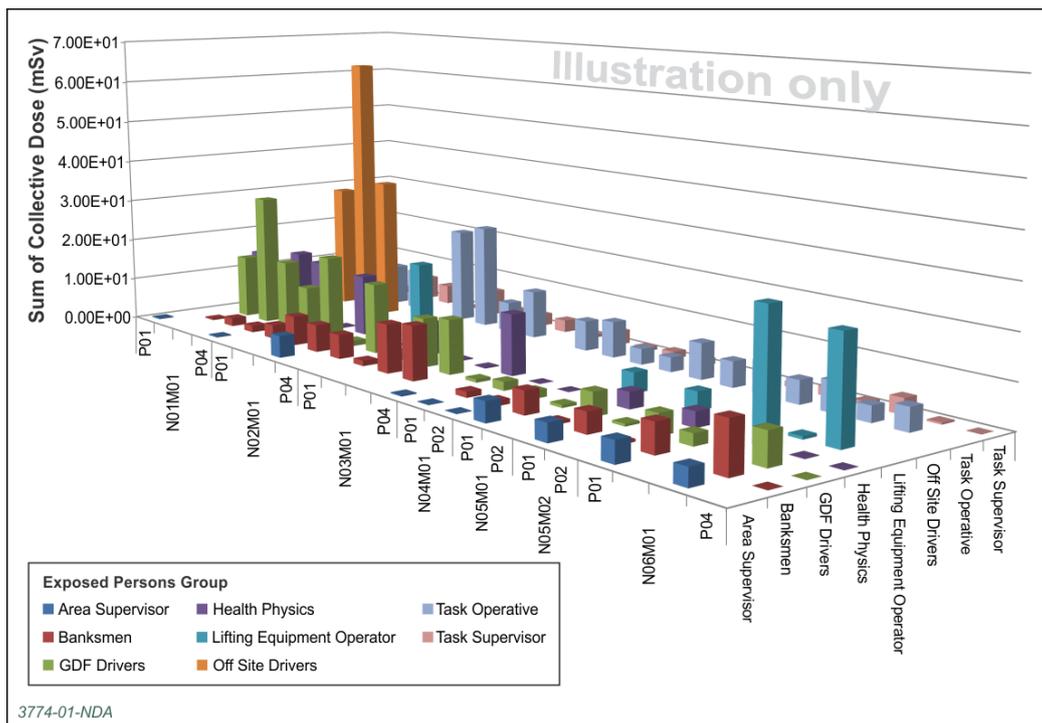


Figure 5 shows the illustrative collective dose (y-axis) mapped to the PFD tasks (x-axis) and worker group (z-axis). The tasks where a need for remote handling has already been identified (eg N06M04) are not shown; only those tasks that are still assumed to require operator intervention are shown. The analysis is for the highest throughput year of 2044.

The analysis presented in Figure 5 shows that off-site drivers carrying out one of the tasks in N01M01 (P3 - Transport the TP rail wagon to rail sidings) could receive a collective group dose of approximately 60 man-mSv. In carrying out all their tasks in N01M01, the total collective dose is 128 man-mSv for this group. Some very pessimistic assumptions have

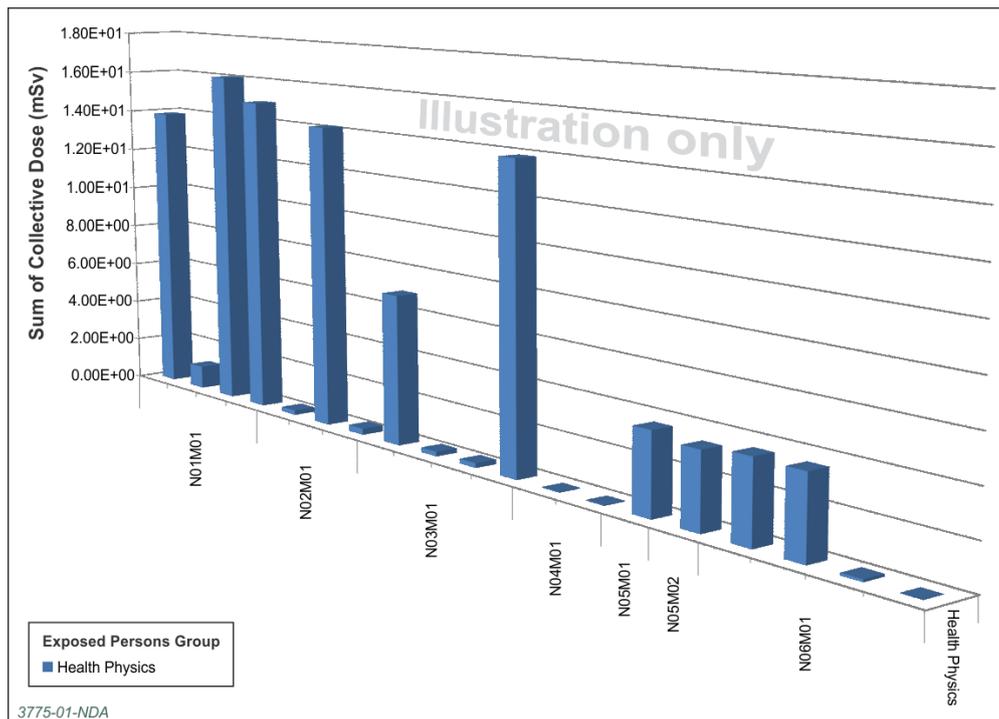
been made in calculating these doses. In particular that the same operator group undertakes all shunting, decoupling and inspection tasks and the task exposure duration is 2 hours for each package. The assessment demonstrates that there will be a potential dose burden to be reduced and/or optimised through appropriate design to enable a demonstration of ALARP. It is highly likely that removal of pessimisms and future optimisation will result in predicted individual doses being well below RWM criteria.

It is important to acknowledge that the normal operations assessment is illustrative at this stage of considering a generic facility. This means that the screening dose assessment has been undertaken in the absence of fully developed 'needs informed design'. The PFD is still relatively high-level and certain generic processes are not fully defined in a requirements sense. The PFD and the normal operations safety assessment does not in itself lead directly to design solutions for 'needs'; rather that 'needs' should be assumed to be met (until they are shown not to be necessary). As a result, certain assumptions have been made based on known needs/requirements, such as: the presence of an inlet cell, health physics monitoring at each handover, control and segregation of potentially hazardous areas and operations, manual operations rather than automated. Suitable option studies and design optimisation to determine the actual requirements and acceptance criteria to be placed on the design are detailed in FAP.2016.VOL2.01. This future work will include the requirement to consider the implementation of additional safety measures based on consideration of time, distance and shielding.

Notwithstanding that these calculations are based on generic assumptions about tasks and locations, the assessment concludes that no significant issues have been identified that could not be managed through the application of 'good design' and suitable 'process development and optimisation'. The attenuation or dose reduction factors required to meet the RWM dose criterion, below which process optimisation can be applied to further reduce exposures, are judged to be fully achievable using existing nuclear industry solutions. For example, the inclusion of a fully shielded inlet cell with remote handling emplacement for UILW and spent fuel is a technically feasible solution and currently included in the illustrative concept. This claim is supported by worldwide experience in operation of comparable facilities. To illustrate this, there currently exist similar facilities for the handling and storage of HHGW and LHGW within the UK. Some of these facilities are designed to operate with dose rates that are higher than would be expected in the GDF. These include:

- the National Nuclear Laboratory post-irradiation examination lab which undertakes examination of used nuclear fuel and irradiated materials, radioactive waste processing and management and handling and management of radioactive sealed sources in 13 shielded concrete cells or 'caves'
- the Sellafield Residue Export Facility which handles vitrified HLW
- the Sellafield ILW packaging and storage facilities
- other historical high active cell lines at Dounreay, Harwell, Winfrith and Berkeley
- waste stores at UK licensed sites such as Amersham, Dounreay, Harwell, Winfrith etc
- Nuclear power plant spent fuel and ILW waste handling facilities

The illustrative potential dose burdens that will require reduction for specific worker groups have been assessed to understand the relationship between process assumptions, locations and activities. For example, the illustrative doses received by health physicists are directly attributable to assumptions regarding the level of monitoring and task duration (Figure 6).

Figure 6 Illustrative Task Dose Assessments – Health Physics (2044)

At present, the assumption is that each 'change of ownership' during package handovers between process areas will require manual checks to be undertaken by health physics technicians (to demonstrate control and segregation of potentially hazardous areas and operations). This is an example of an assumption related to a process which has not yet been confirmed to be necessary, ie not stated as a requirement. If the assumed activity were confirmed as a requirement; options that would reduce or eliminate the dose burden (such as automation) would be explored through optioneering and design.

This illustrative assessment provides confirmation that the model developed by RWM can be used as a basis for future modelling of exposures within the GDF. In addition, the screening dose assessment gives very high confidence that feasible design provisions, such as a shielded facility for the handling of UILW, are available and will meet RWM's safety criteria [8 and 11].

3.4 Future design development

Future design development must enable a clear demonstration that the hierarchy of safety measures detailed in the NOSM has been applied. This will provide an explicit demonstration that:

- the most appropriate means of meeting the design requirements has been selected, and
- the requirements for optimisation have been satisfied

Thus, the hazard management strategies (and associated design solutions that have been identified) are an important part of the feasibility demonstration. The application of the NOSM risk reduction hierarchy drives the following development process:

- Can the hazard be eliminated by design through modification of the engineered design or the process itself?

- If the hazard cannot be eliminated, what dose or risk reduction measures could be incorporated into the developing design in order to:
 - provide a means of preventing a challenge to the safety function which if compromised could result in exposure to the hazard
 - provide a means of protection prior to a radiological hazard being realised
 - provide a means of mitigating the radiological hazards

The illustrative safety measures provided for the GDF may be engineered or operational/procedural. Additionally they may be active or passive in their delivery of the required safety function. Based on the hierarchy detailed in the NOSM:

- engineered measures are preferred to procedural
- passive measures are preferred to active

The full GDF safety assessment will be developed in parallel with the design. As the design for the GDF develops, more detailed assessments can be undertaken to understand where dose reduction measures and optimisation can be applied to demonstrate that doses will be tolerable and ALARP. The output from the assessment will be used to inform the design as it progresses to satisfy the hazard management strategy, including the RWM integrated design and safety process. This approach is consistent with current industry standards and relevant good practice.

In broad terms, the processes and operations to be conducted at the GDF are functionally the same as those undertaken at numerous HAW Storage and Handling Facilities in operation in the UK. Safety justifications for the operation of such facilities are mature, the engineered systems required to reduce risks well understood, and as such future work will be focussed on implementing proven de-risked solutions in an engineered underground facility.

3.5 Background dose assessment

The TODA analysis deals with individual 'package types' processed as described in the PFD. The analysis did not include any contribution from background radiation from other packages. At this generic stage the background doses were excluded from consideration as the focus of the assessments is on identifying the high dose process task operations. The key objective was to identify the high radiological hazard potential areas of the GDF. For most operations the background dose is not expected to be a major contributor if the principles of ALARP are applied to the developing design. Future work will involve a more detailed assessment of the background dose which should be a secondary consideration for most of the GDF.

For the normal operational assessment, the off-site dose assessment reported in Section 3.7 has not included the contribution of external radiation dose to the public exposure. This is consistent with the expectation that the contribution of external radiation to the off-site dose will be insignificant in comparison to the contribution from authorised discharges, as demonstrated at nuclear sites worldwide. As discussed previously, the optimisation of the final site design will include consideration of all factors affecting off-site dose. The design will be derived from detailed consideration of the appropriate location of transport package receipt and holding areas, their capacity and distance to the nearest point of habitation, which will be dependent on the nature of the GDF site. Where required, transport package receipt and holding areas will include additional design features to demonstrate that risks are ALARP. In addition, the external dose rates off-site will be strongly influenced by a number of factors, including distance of the sources from the site boundary and any site topography.

As a result, the calculation of off-site doses from external radiation will be undertaken on a site-specific basis, when there is sufficient design definition in terms of the layout of surface facilities and the routing of waste packages on the site. The on-site surface location where

there is the highest concentration of transport packages is likely to be the buffer park. Due to the generic design of the GDF at this time, further work will be required to ascertain the off-site dose rate from transport packages located on the surface at the GDF and, if relevant, identify the dose reduction factors required. This is captured in FAP.2016.VOL2.03.

3.6 Contamination spread

Packages transported to the GDF will be 'clean'; however they may have a very small amount of external contamination (within that permitted under the Transport Regulations). It is recognised that there are mechanisms by which any loosely bonded contamination could be transferred to the GDF environment and equipment. Due to the large number of packages being handled at the GDF, contamination could build up over time to a level sufficient to designate parts of the GDF as controlled areas under the Ionising Radiations Regulations 1999.

Contamination is defined as, "*the presence of a radioactive substance on a surface in quantities in excess of 0.4 Bq/cm² for beta and gamma emitters and low toxicity alpha emitters or in excess of 0.04 Bq/cm² for all other alpha emitters*"⁸. Based on these values, the illustrative screening assessment concludes that after a few years of operation, particular areas may need to be classified as a controlled area. The design intent is that certain areas will be operated as a 'clean' facility with all necessary controls as required by IRR99 to ensure that risks to workers are ALARP from normal operations. Such areas might include the inlet cell and some process ventilation plant rooms. (FAP.2016.VOL2.02).

3.7 Public dose assessment

RWM has calculated the annual individual dose to a member of the public from aerial discharges; these are presented in the Operational Environmental Safety Assessment [14]. The assessment is an illustrative quantitative assessment, using conservative assumptions, of the potential effects on members of the public and non-human biota. The calculated aerial discharges include the impact of gases generated in packaged wastes for all significant radioactive gases (C-14-bearing methane and carbon monoxide, tritium and Rn-222). Potential discharges of naturally-occurring Rn-222 from the host rock have also been considered. It should be noted that the off-site dose calculations include the effect from backfilling.

The reference case gas release scenario is expected to provide a reasonable generic representation of most aspects of the likely gas generation behaviour. A bounding case scenario, taking the highest peak release rate for each radionuclide across three variant scenarios, has been considered in a quantitative assessment of dose.

The total dose to members of the public from peak gas release rates during the operational period has been calculated to be 0.17 mSv per year. The reference case is based on conservative assumptions appropriate to this generic stage of the GDF programme. The majority (65%) of this dose arises from radon-222 with minor contributions from C-14-bearing gases and tritium. For the bounding case, based on conservative assumptions, the annual public dose is calculated to be 0.28 mSv per year, for which the contribution from tritium and C-14-bearing carbon monoxide rises to 57%. This bounding case dose is approximately one tenth (1/10th) of the average dose from naturally occurring background radiation in the UK. Furthermore, the dose arising from the waste packages is not 'new' in so much as the radioactive material and packages will already exist.

These total doses are below the RWM dose criterion for members of the public as stated in Table 1. Further dose reduction will be explored as an integral part of formal optioneering and design development to ensure that risks will be demonstrably ALARP. This future work

⁸ See p214 in Transport Regulations SSR6 2012.

will include demonstration that all design elements are capable of delivering the required safety functions and associated requirements.

As stated earlier, the calculations at this stage are illustrative in nature; any accurate or definitive prediction of radiological dose from off-site discharges from the GDF (and hence more detailed calculations required for future safety cases) will be determined by site-specific factors. A more specific calculation of any off-site dose will be a function of actual gaseous discharge rates during each year of GDF operation in combination with local environmental factors and the location and habits of exposed groups.

When the GDF design has been developed to a sufficient level of design definition, the potential for fugitive releases from individual surface buildings will be assessed. In particular, this assessment will need to examine the potential requirement for buffer zones to ensure that there are no uncontrolled and unauthorised discharges from buildings and areas on the site. This is captured in FAP.2016.VOL2.04.

3.8 ALARP

The objective of this initial illustrative assessment is to identify areas for design development which will support changes to the design provisions supporting the operation of processes outlined in the PFD. This will be beneficial in terms of meeting RWM's safety criteria. Potential modifications to the concept systems or processes, aligned to the functional requirements in the PFD, will be considered as part of the GDF design development process. They will be implemented in accordance with the NOSM [8]. At this stage of generic development it is not appropriate to make a formal ALARP statement with regards to the GDF design and operation. However the work in this normal operational assessment supports the judgement that a GDF can be designed, constructed and operated in a way that is shown, from a risk perspective, to be tolerable and ALARP.

In the UK there is a split between the waste that has already been packaged, and stored, and the remaining inventory that will be packaged before disposal in a GDF. It is the waste packager's responsibility to determine the package content is in compliance with RWM's Disposability Assessment process and the associated Letter of Compliance. This process ensures that robust records will be provided at the time of disposal to ensure that waste acceptance criteria are followed. It will be part of routine operations at the GDF for a role, similar to that at the consignor site, to undertake a comprehensive compliance check in order to accept the consignment onto the GDF site.

Both in the UK nuclear industry and world-wide, the handling and storage of radioactive waste is a well understood and highly practiced activity. This experience gives a very high-level of confidence that the GDF can be developed using design solutions that meet RWM's safety criteria. The design will consider the specific requirements of operating a nuclear facility in the sub-surface environment, which may present certain engineering challenges. However none are considered unique from a technical or radiological perspective. This will be further considered as part of the design development in accordance with the NOSM and the RWM design process.

4 Implementation

The normal operations safety assessment has identified, at a generic level, the areas of operations and locations for which engineering provisions will be required in developing full designs. Further work will be required in terms of optioneering and design development in order to develop solutions which will ensure that RWM safety criteria are met.

This will include but is not limited to:

- validation of base assumptions before further design work is undertaken
- identification of all areas requiring robust design provision
- identification of all areas requiring process or task optimisation
- definition and adoption of design requirements to satisfy criteria

This study has identified a number of FAPs to ensure that an optimal design for the GDF, with respect to normal operational dose uptake, is achieved and that this work will be based upon an appropriate set of input data. The most significant FAPs relevant to the normal operations safety assessment are presented in Table 8.

Table 8 FAP Listing

FAP ID	FAP Description
FAP.2016.VOL2.01	Undertake further assessment to identify areas of concern for a normal operation dose assessment to minimise the risk of a poorly defined set of requirements related to normal operations
FAP.2016.VOL2.02	Undertake a study to determine the radiation and contamination zoning requirements and the controls necessary to minimise exposures and prevent unauthorised contamination transfer
FAP.2016.VOL2.03	Undertake a study to review the impact of the location of the buffer areas on the surface to minimise elevated dose rates for operators and the public in surface buffer areas.
FAP.2016.VOL2.04	Undertake a study to determine which buildings and areas require buffer zones to minimise the risk of non-compliance with the Environmental Permitting Regulations 2010 (fugitive releases from buildings)

5 Conclusions

The extent to which the principal claim (OSC.SC2) has been demonstrated is summarised below:

The illustrative safety assessment presents evidence related to the process that has been followed, the scope of the assessment, nature of hazards identified requiring design provisions, regulatory expectation related to their control, and hazard management strategies that will need to be adopted to prevent or minimise the routine dose exposure.

An illustrative normal operations safety assessment has been undertaken and the exposure pathways by which the GDF operators, other on-site workers and members of the public can receive a radiological dose have been assessed, namely:

- external radiation, ie direct dose
- internal radiation such as inhalation of particulate material or gaseous discharges as a result of activities on the site

At the current generic stage of GDF implementation, the design definition of the normal operations activities does not enable the production of a full definitive safety assessment. The current assessment is based on illustrative screening doses which demonstrate that it will be feasible in the future to produce a full assessment. The current assessment identifies those areas of the GDF, and the associated receptor groups, where doses will need to be managed, reduced and/or optimised through appropriate design.

This initial assessment provides a high level of confidence that a means of meeting the safety demands placed on the GDF are feasible (with today's technology) and that the GDF will be safe to operate.

At this stage the means of delivering the basic functional process has not been optimised with respect to radiological safety. Furthermore, the current illustrative GDF concept does not include all the safety features that will be required to ensure, in so far as is reasonably practicable, that RWM's safety criteria are met.

From this normal operations safety assessment for the GDF, it is concluded that:

- RWM has developed a significant capability for assessing doses based on a functional PFD of the GDF. This allows the contribution to the overall normal operational dose burden by waste stream, package, location and schedule to be rapidly and clearly assessed with confidence. It also provides an assessment of the viability of the GDF process based on man-effort requirements and identification of any 'pinch points' (ie where collective hours allocated to an exposed group exceeds the maximum hours available in a year). This capability represents a significant improvement in capability since the 2010 generic DSSC was produced.
- Process areas and their associated operations and locations have been identified for which engineered provisions will be required; for example, where UILW is to be handled, provisions such as shielded remote handling facilities or 'hot cells' (the inlet cell) will be implemented.
- RWM now has the capability to identify: those areas of the GDF where effort needs to be focussed on optimising the design; and those areas where the fidelity of information on 'process needs' and 'task requirements' needs to be developed.
- The required dose reduction factors can be achieved through standard nuclear industry solutions. Proposed solutions will be derived through optioneering and appropriate task-design to ensure doses from normal operations in the GDF will be demonstrably ALARP.

- Annual doses to a member of the public from aerial discharges, based on peak gas releases during the operational period, are predicted to be very low and acceptable.

Where the assessment uses or identifies illustrative safety measures, to meet the dose reduction targets, it does not conclude that those measures are the correct solution. At this generic stage this assessment has not been supported by full optioneering, including application of the 'eliminate, prevent, protect and mitigate' hierarchy to develop candidate safety measures. The assessment is not intended to show that all means of meeting regulatory expectations have been identified, neither is it assumed that legal requirements have been met in full at this generic stage. However at the generic stage it gives high-confidence that regulatory expectations and legal requirements can be met.

Following on from this illustrative assessment the integrated design and safety approach, in accordance with the NOSM and the RWM design process, will be applied to the developing design. This approach is entirely consistent with that applied by other operators in the UK nuclear industry and will focus on the application of optioneering and optimisation studies in order to develop suitable design solutions.

In broad terms, the processes and operations to be conducted at the GDF are functionally the same as those undertaken at numerous HAW Storage and Handling Facilities in operation in the UK. The safety cases for the operation of such facilities are mature and the engineered systems required to reduce risks well understood. As such future work will be focussed on implementing proven technology in an engineered underground facility.

In addition, the RWM Disposability Assessment process specifies performance requirements for waste packages to enable them to be safely stored today, and for them to meet future GDF waste acceptance criteria. As a result, this experience gives an additional level of confidence that the GDF can be designed to be operated safely, ensuring that any radiological exposures and the arising doses will be minimal and acceptable.

This illustrative assessment, based on relevant good practice and UK nuclear site licence operational experience, shows that no significant obstacles have been identified which could adversely impact on claims of future compliance against RWM safety criteria. The areas which require further work to fully underpin the principal claim are largely related to actual full design development and the resolution of the topics identified in the forward action plans.

References

- 1 Radioactive Waste Management, Geological Disposal: *Overview of the Generic Disposal System Safety Case*, DSSC/101/01, 2016.
- 2 Department of Energy and Climate Change, *Implementing Geological Disposal - A framework for the long term management of higher activity waste*, URN 14D/235, July 2014.
- 3 Radioactive Waste Management, Geological Disposal: *Technical Background to the generic Disposal System Safety Case*, DSSC/421/01, 2016.
- 4 Radioactive Waste Management, *Geological Disposal: Volume 3 - Accident Safety Assessment*, DSSC/313/01, 2016.
- 5 Risktec, *HAZDOC Section I: Normal (Radiological) Operations*, RWM-04-R-08, Issue 3.0, June 2016 (unpublished).
- 6 Radioactive Waste Management, *Geological Disposal: Basis of Operational Assessment*, 2016 (unpublished).
- 7 Radioactive Waste Management, *Geological Disposal: The 2013 Derived Inventory*, DSSC/403/01, 2016.
- 8 Radioactive Waste Management, *Nuclear Operational Safety Manual*, RWM14-31 Rev 0, 2015 (unpublished).
- 9 Radioactive Waste Management, *Geological Disposal: Generic Environmental Safety Case*, DSSC/202/01, 2016.
- 10 Radioactive Waste Management, *Geological Disposal: Generic Transport Safety Case*, DSSC/201/01, 2016.
- 11 Radioactive Waste Management, *Radiological Protection Criteria Manual*, RWM02, Revision 2, 2016 (unpublished).
- 12 OECD NEA, *Occupational Radiological Protection Principles and Criteria for Designing New Nuclear Power Plants*, ISBN 978-92-64-99142-2.
- 13 Radioactive Waste Management, *Geological Disposal: Generic Facility Designs*, DSSC/412/01, 2016.
- 14 Radioactive Waste Management, *Geological Disposal: Generic Operational Environmental Safety Assessment*, DSSC/315/01, 2016.

Glossary

A glossary of terms specific to the generic DSSC can be found in the Technical Background document.



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