Radioactive Waste Management

NDA Report no. DSSC/311/01

Geological Disposal

Generic Operational Safety Assessment Volume 1 - Non-radiological and Construction Safety Assessment

December 2016

Radioactive Waste Management

NDA Report no. DSSC/311/01

Geological Disposal

Generic Operational Safety Assessment Volume 1 - Non-radiological and Construction Safety Assessment

December 2016

Conditions of Publication

ISBN 978-1-84029-545-0

Other Publications

If you would like to see other reports available from RWM, a complete listing can be viewed at our website https://rwm.nda.gov.uk, or please write to us at the address below.

Feedback

Readers are invited to provide feedback on this report and on the means of improving the range of reports published. Feedback should be addressed to:

RWM Feedback
Radioactive Waste Management Limited
Building 587
Curie Avenue
Harwell Campus
Didcot
OX11 0RH
UK

email: rwmfeedback@nda.gov.uk

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 construction and non-radiological safety assessment is that:

OSC.SC1: All reasonably practicable steps will have been taken to implement design provisions whose function is to prevent or minimise the risk of injury due to conventional hazards.

At this stage of the project the focus of the construction and non-radiological safety assessment is on those ‘conventional’ hazards with significant harm potential. Such hazards will require a hazard management strategy and robust engineered design provision to ensure the safety of staff, the public and environment. This approach is appropriate where the aim is to demonstrate that the management of significant hazards is possible. The level of assessment is appropriate for the current design development stage of the geological disposal facility (GDF); it is a feasibility study. At this time, a detailed description of the specific site layout, design, operational activities and associated tasks is not available, or is expected to be available. The construction and non-radiological hazards safety assessment is therefore derived from the representation of the GDF as a functional process flow description (PFD). This is a high level description of activities and the required plant and equipment or tasks that could be used to implement the required functions.

A systematic hazard identification exercise has been undertaken. The output of the hazard identification process was collated and recorded in the illustrative consolidated hazard log. As part of the screening process to identify the most likely hazards with the greatest harm potential, the complete consolidated hazard log was reviewed. The conventional hazards (ie construction and non-radiological) have been grouped into twelve high-level conventional generic fault sequence groups (CgFSGs).

A further screening of the hazards contained within the consolidated hazard log was undertaken to clarify the phase of construction (such as surface, surface-to-sub-surface or sub-surface construction) and the specific operations. This was developed into generic conventional hazard groups to be assessed:

- C1: workplace transport
- C2: working and load at height
- C3: structural collapse
- C4: plant/machinery
- C5: fire and explosion
- C6: projectiles and blast, over-pressure
- C7: airborne hazardous substances and air quality (including asphyxiation)
- C8: flooding
- C9: electrical
- C10: noise and vibration
- C11: concurrent activities (also referred to as ‘conflict hazards’)
- C12: occupational

For each generic conventional hazard identified (ie the CgFSGs), the relevant legislation (or relevant good practice) and high level health and safety requirements have been compiled. These will form the basis from which the hazard management strategy will be developed, with the emphasis being on hazard elimination where practicable. This will also include

consideration of design provisions that allow the GDF to be designed to be "passively safe" during the operational phase. Work during the construction phase, such as installing rock support systems, will ensure the facility is "passively safe" in terms of the disposal of radioactive waste packages. Compiling the high level health and safety requirements has also identified general expectations, placed on the duty holders under the key legislation and recognises the role of relevant good practice (RGP) and/or guidance from the Health and Safety Executive (HSE) or industry bodies.

During its construction and operation, the GDF will share many features not only with large-scale sub-surface operations but also with other large-scale construction projects undertaken for high-hazard industries in the UK and overseas. As such, development of the GDF needs to consider potential hazards common to many industrial operations subject to a 'permissioning regime' (for example, nuclear, railways, offshore and onshore major hazard industries). These hazards can be present during construction and normal operations as inherent hazards and as a result of potential failure of process plant.

This information will be used to inform the future Optioneering studies to be undertaken as the GDF design progresses to satisfy the hazard management strategy. This will ensure that an appropriate and balanced GDF design is implemented by ensuring legislative compliance, incorporation of relevant good practice and proportionality between the needs of conventional, radiological and environmental safety across all safety-related hazards.

The GDF design will be developed to ensure that all reasonably practicable steps to minimise and control conventional hazards have been taken. This will be achieved in line with the recognised hierarchical principle of ERICP:

- Eliminate
- Reduce
- Isolate
- Control
- Protect

This approach has been applied illustratively for all 12 CgFSGs to demonstrate that RWM understands the principal construction and non-radiological hazards that are relevant to the GDF. This gives high confidence that the processes and outcomes and the relationship to the design development are understood and will be demonstrated in the application of the RWM design and safety integration process. The RWM design and safety integration process is consistent with current industry standards and relevant good practice.

Further work has been identified by RWM to develop the safety management arrangements and ensure that appropriate consideration of construction and non-radiological hazards is undertaken throughout the lifecycle of the GDF. This work is captured in a Forward Action Plan (FAP).

Learning from experience

As part of the development of the generic OSC, a review has been undertaken of incidents from other GDF and relevant major construction projects to identify additional good practice guidance and measures. This will be carried forward and integrated into the RWM GDF design process to enhance safety during both construction and operation.

Analysis of major incidents in other high-hazard industries generally finds that the root cause falls into one of four categories:

- an event occurs that was either deemed extremely unlikely or unknown/unidentified, such that no risk controls were identified or implemented to manage it

- the impact or severity of an unlikely event that occurs is in excess of that used in the design basis and is hence beyond the risk control system's capability to manage
- a facility is operated outside its design basis either intentionally or unknowingly
- individually unimportant errors and/or failures combine to result in a serious outcome

Additionally, the analysis of major incidents in high-hazard industries with different technical causes and work contexts has identified several common causal factors. These factors are related to leadership, attitudes and behaviours, risk management and oversight and can be measured through methods such as the international safety rating system. RWM is using this insight to ensure that a strong safety culture is at the heart of the GDF Programme.

Safety culture

Worldwide industrial incidents have demonstrated the importance of developing and maintaining a strong safety culture within the leadership and management teams to ensure that safety is given the highest priority. The safety culture in RWM is underpinned by the safety management system which ensures that all necessary processes and procedures are aligned to ensure that safety is a core aspect of normal business. This includes the development of integrated working arrangements through the design and safety integration process to deliver safe, optimised designs with suitable and sufficient management controls to ensure that safe working practices are applied. RWM has instilled a corporate safety culture within its management system and this is being implemented through initiatives such as 'see something say something', near-miss reporting, emphasising importance of day to day safety and the monitoring aspects such as staff surveys and safety-related performance indicators in each monthly management report.

RWM is committed to building on this good practice as the organisation moves forward, as would be expected from a prospective future nuclear site licence holder. In maintaining a strong safety culture RWM will continue to take account of learning from experience both from GDF projects and from other major projects worldwide. The safety culture, together with the associated safety management system, will be the basis for ensuring that RWM applies rigour to the assessment and implementation of the highest standards of construction and non-radiological safety to all its activities.

Concurrent activities and hazards

Over the long operational phase of waste emplacement (in excess of 100 years), it will be necessary for emplacement operations to be undertaken in parallel with construction activities (eg ongoing excavation and construction of disposal vaults). This strategy of parallel construction and emplacement is partly a practicality issue from working in a geological environment and also is required to minimise the duration of the operational phase. These parallel activities give potential for hazards termed as 'conflict hazards' in the safety assessment. There could be potential for these 'conflict hazards' to cause interactions between waste emplacement operations and construction. However early identification, and control, of 'conflict hazards' will ensure that the system is designed to ensure that there is no impact on the ability of engineered safety measures to deliver their nuclear safety function. Construction related hazards which may impact on delivery of safety functions required for safe nuclear operations (eg emplacement of waste), are assessed in the radiological accident safety assessment as an internal hazard, as required by the RWM Nuclear Operational Safety Manual.

The issues arising from this strategy have been identified and assessed relative to the design. For example, the illustrative underground layouts have been configured to minimise the amount of construction work required up to first waste emplacement. The safety of concurrent operation and construction can be assured by utilising the following illustrative options:

- airlocks and seals between different zones and areas underground
- the provision of independent ventilation circuits

The importance of ensuring a balanced design to manage safety hazards (both conventional and radiological) is fully recognised by RWM. The early recognition of 'conflict hazards' at this stage will ensure that the design and operation of the GDF is considered as a 'system' that minimises the potential for unsafe interactions. This need for a balanced design that takes account of the full GDF lifecycle has been recognised and is applied during all development work.

Concluding remarks

The extent to which the principal safety claim (OSC.SC1) has been demonstrated is summarised below.

This 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 risk of injury due to conventional hazards.

The safety assessment concludes that the following conventional fault groups are the most significant in terms of potential for harm during the construction phase:

- structural collapses underground including rockfalls
- fire and explosions (in particular in the underground environment)
- flooding (in particular in the underground environment)
- transport accidents
- air quality underground

The hazard management strategies, future development of detailed design requirements and implementation in the design will ensure these hazards do not warrant further consideration as part of the 'design basis accident' in the operational phase. The nature of the construction will ensure that it is safe to operate for its intended purpose. Compliance with all safety requirements during the operational phase will be subject to ongoing regulatory review, commonly referred to as Periodic Review of Safety. The design and means of ensuring safety through life delivery will be an integral part of the design development process. The implication of different host rocks has also been assessed, including the differences between specific hazards associated with each host rock, together with the different techniques which may be applicable to the underground construction activities for each host rock.

It is concluded that this high level assessment has identified a representative set of conventional safety hazards and the associated risks from construction. This includes the potential hazards from construction in parallel with disposal and operational waste package handling and emplacement activities. In addition, the relevant good practice and requirements to manage the hazards have been identified and processes will be put in place to ensure the integration of these controls within the GDF design. This will be achieved through implementation of the hazard management strategy.

This assessment provides high confidence that RWM has an understanding of the conventional hazards that will need to be assessed and controlled during construction and operation. This will ensure that potential hazards will be adequately addressed in the design and managed throughout the GDF construction and operational activities. The areas which require further work to fully underpin the principal claim are largely related to actual design development, including the design of civil structures and construction plans and the resolution of the FAPs.

Following the completion of this illustrative safety assessment for construction and non-radiological hazards, a number of items of further work have been identified and designated as FAPs. The FAPs will be taken forward as part of the GDF design development process in order to facilitate the development of a balanced design based on relevant good practice and experience. As such, no significant obstacles have been identified which could challenge feasibility where there are claims of future compliance against targets, tolerability of risks and the 'as low as reasonably practicable' (ALARP) principle associated with construction and non-radiological hazards.

.

List of Contents

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 waste. Information on the UK Government and devolved administrations'[1] 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].

The 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 the 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 the 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 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.

---

[1] 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.

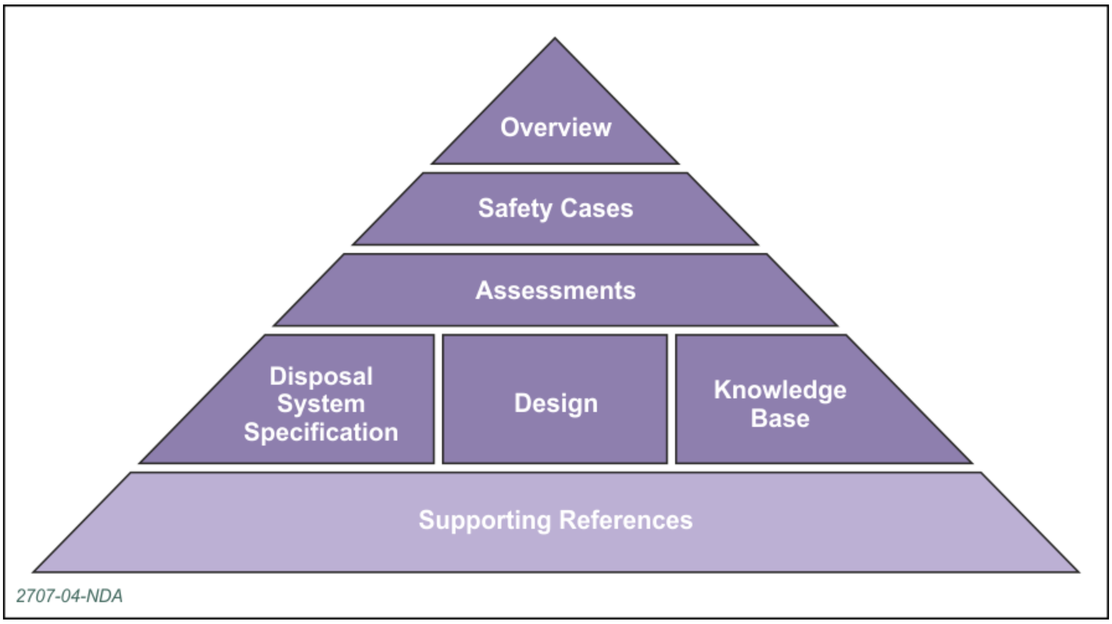
High level information on the inventory for disposal, the illustrative disposal concepts and other aspects of the disposal system is collated in a technical background document (the Technical Background) [3] that supports this generic Disposal System Safety Case.

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 Generic Operational Safety Assessment: Volume 1 – Construction and Non-Radiological Safety Assessment

This document is the Construction and Non-Radiological Safety Assessment and is one of 4 volumes that, together with a summary report, make up the Operational Safety Case (OSC).

The generic DSSC was previously published in 2010. A number of drivers arose for updating the safety case as an entire suite of documents, most notably the availability of an updated inventory for disposal.

This document updates and replaces the 2010 Construction and Non-Radiological Safety Assessment published as part of the 2010 generic DSSC.

Construction and non-radiological (conventional) health and safety on nuclear sites refers to risks arising from operations not associated with nuclear material, ionising radiation (the *Ionising Radiations Regulations 1999*) or nuclear licensed activities (*Nuclear Installations Act 1965 as amended*). It includes, for example, risks from work at height, hazardous substances, noise, confined spaces, vibration, electricity, asbestos, machinery, construction, lifting equipment and transport in addition to environmental hazards.

These conventional hazards can be present as inherent hazards such as working at height, and as a result of failures of process plant, such as missiles associated with failure of rotating machinery during construction or operational activities.

In addition to presenting hazards to nearby persons, the conventional hazards which may occur during construction or operations may affect other systems causing other hazards. These are commonly referred to as ‘domino’ effects, an example being loss of ventilation due to disturbance by blasting operations. ‘Domino’ effects may also threaten the integrity of nuclear related plant and equipment and result in radiological hazards occurring or the loss of plant included within the design to protect against radiological incidents. Such threats to nuclear related plant and systems are not assessed in this document and will be assessed in the radiological accident safety assessment [4].

To ensure the safety of persons during operations, consideration of the management of conventional hazards is and will be an integral part of the design development of the GDF.

1.3 Objective

The principal safety claim to be demonstrated for the construction and non-radiological safety assessment is that:

OSC.SC1: All reasonably practicable steps will have been taken to implement design provisions whose function is to prevent or minimise the risk of injury due to conventional hazards.

At this stage of the GDF programme, suitable hazard management strategies will be developed and implemented for the hazards with significant harm potential. As a result, this provides confidence the GDF can be constructed and operated safely and that all reasonably practicable steps will be taken to implement design provisions, engineered protection or process design and optimisation, whose function is to prevent or minimise the risk of injury due to conventional hazards in both the construction and operational phase. As a result, risks to the workforce and members of the general public will be tolerable and as low as reasonably practicable (ALARP).

This volume presents the non-radiological safety assessment for the construction and operation of the GDF in support of the 2016 generic DSSC suite in order to:

- demonstrate that the conventional hazards with the most significant harm potential from construction and operation activities have been identified
- present the overarching high-level health and safety requirements associated with these hazards
- demonstrate that good practice and legislative requirements have been identified and that RWM has an understanding of the conventional hazards, the associated legislation and regulatory requirements and has suitable and sufficient arrangements in place to develop safe design

- summarise the lessons learned from relevant incidents and recent projects and explain how these will be taken forward during the development of the GDF design and safety case
- review and assess the issues arising from concurrent activities at the GDF site
- review the relationships between the different host rock types and the applicability and nature of conventional hazards relevant to each

1.4 Scope

The scope of this report covers all conventional (construction and non-radiological) safety hazards. It excludes an assessment of radiological consequences associated with construction and operation of the GDF.

A systematic and proportionate hazard identification study has been undertaken. The output from the hazard identification studies has been documented in the consolidated hazard log. The study is based on the current Basis of Operational Assessment [5], which describes the GDF concept as a functional process flow description (PFD) and a high level description of activities, plant, equipment and tasks, which could be used to implement the required functions. A more detailed discussion of the means by which these functions can be delivered is presented in the RWM Design report [6].Recognising that the construction methods will vary significantly based upon the chosen site(s) and geological environment, an appropriate consideration of construction related conventional hazards has been undertaken.

At this generic stage, the conventional hazards identified and assessed represent an illustrative set of the hazards which if left unaddressed would present the greatest potential for harm. At this generic stage, this assessment does not address the more general requirements for health and safety legislation, eg with respect to employee consultation, incident reporting and insurance.

Specific controls are not claimed for conventional hazards as the design detail does not yet support this. As a result, there is no detailed substantiation to underpin any of the safety functions or claims. This is considered to be appropriate for the current generic stage of developing and analysing a GDF. However, high level requirements to meet current best practice will be identified for the hazard groups. This enables the development of comprehensive hazard management strategies.

There are a number of important subjects covered elsewhere in the generic OSC:

- the hazards arising from construction that could impact on nuclear/emplacement operations, or on safety measures performing a nuclear safety function, are treated as internal hazards within the radiological fault analysis. These hazards are assessed in the Generic Operational Safety Assessment, Volume 3: Accident Safety Assessment
- the hazards associated with the GDF which could result in impacts to the environment are covered within the generic Environmental Safety Case [7]
- those hazards associated with the transportation of waste packages to the GDF, before they pass across the licensed site boundary, are covered in the generic Transport Safety Case [8]

This report does not consider the conventional hazards arising as a result of external events; these will be addressed in future iterations as the design of the GDF develops. In addition, 'paired hazards' which have the potential to result in both conventional and radiological consequences are discussed within the 2016 generic OSC Main Report [9]. For example, fire and flooding underground both have the potential for significant 'harm' associated with the conventional hazard, together with the potential for a radiological impact. The development of suitable hazard management strategies for 'paired hazards' will ensure that the design is developed, using the 'ERICP' philosophy, to reduce risk to an acceptable level.

There are no interfaces identified between this volume and Volume 4: Criticality Safety Assessment [10] and Volume 2: Normal Operations Safety Assessment [11] (Volume 2 is currently only focused on radiological safety).

1.5 Document structure

This report is structured as follows:

- Section 2 describes the safety assessment approach for construction and non-radiological hazards which has been adopted at this stage of the GDF programme.
- Section 3 discusses the results of the construction and non-radiological safety assessment process. This includes: the safety principles which will be developed from the hazard management strategy during design development, the hazards in the form of conventional generic fault sequence groups and the illustrative means by which the requirements of the hazard management strategy can be met.
- Section 4 provides a summary of the lessons learned from other major projects and how these lessons will be incorporated into RWM's GDF development work.
- Section 5 describes how different host rocks give rise to some differences in conventional hazards. The different construction techniques used in different geological environments are also addressed.
- Section 6 details the forward action plans (FAPs) which will help guide the future design development to ensure that specific issues raised in this safety assessment are addressed.
- Section 7 presents the conclusions of the construction and non-radiological safety assessment.

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 Approach

2.1 Introduction

This section presents an overview of the approach undertaken in the management of construction and non-radiological safety hazards in the generic DSSC. The objective of the construction and non-radiological safety assessment is to demonstrate that:

OSC.SC1: All reasonably practicable steps will have been taken to implement design provisions whose function is to prevent or minimise the risk of injury due to conventional hazards.

This high level safety claim (OSC SC1) is demonstrated through the following:

- The most significant conventional hazards associated with the GDF construction and operation activities have been identified through a systematic hazard identification process.
- There is an understanding of the legislative health and safety requirements and current best practice associated with the construction and non-radiological hazards relevant to the GDF.
- Arrangements will be in place to ensure that suitable hazard management strategies are developed which includes the development of design principles to be implemented through the RWM design and safety integration approach at the appropriate project phase.
- Lessons learned from relevant incidents and recent major projects have been identified and assessed in order to ensure a continuous ‘learning from experience’ approach is implemented for the GDF programme.
- A balanced design will be implemented through the hazard management strategies ensuring proportionality between the needs of conventional, radiological and environmental safety across all safety related hazards.
- There is high confidence that the GDF can be constructed and operated safely with risks to the workforce and members of the general public which can and will be tolerable and ALARP.

The development of the GDF design will be implemented in accordance with the RWM design and safety process as set out in the safety case manuals and the RWM Engineering Design Manual [12]. This approach is underpinned by a safety management system which will ensure that an iterative and integrated design and safety process delivers safe, optimised designs with suitable and sufficient management controls to ensure that safe working practices are applied. The safety management system is underpinned by a strong safety culture, which RWM is committed to developing, which takes account of:

- legal and regulatory expectations
- relevant best practice from within the nuclear industry and more general industrial practices, including construction and operations in an underground environment
- learning from experience on other major projects worldwide

2.2 Conventional hazard identification and assessment

In support of the GDF construction and operations, a systematic hazard identification study was undertaken which identified conventional and radiological hazards. Following this review, the identified conventional safety hazards were collated into the consolidated hazard log which grouped the identified conventional hazards into 12 high-level conventional generic fault sequence groups (CgFSGs). For each of the CgFSGs the associated hazards (eg fire) were identified, along with the current relevant legislation. This paring of the hazards and current relevant legislation then informs the development of the hazard management strategy. The hazard management strategy sets out the requirements which will be implemented in the design. The derivation of suitable design principles will enable the identification of suitable and sufficient safety measures to protect against the hazards.

A further review of the hazards in the consolidated hazard log was undertaken to clarify the phase of construction (such as surface, surface-to-sub-surface or sub-surface construction) and operations where the hazards were relevant.

In recognition of the generic stage of the DSSC, with no identified site, the strategy to demonstrate safety is termed ‘generic’ because it must cover a range of possible disposal environments and facility designs. At this generic stage it is not considered appropriate, or possible, to identify specific engineered or procedural safeguards or safety measures to eliminate, prevent, protect or mitigate the identified conventional hazards. Therefore, this illustrative safety assessment sets out the high level requirements needed to meet best practice in safeguarding against each of the CgFSGs identified. This best practice is a summary of requirements which includes engineered and procedural safety measures as potential risk reduction options, placed on the duty holders under the key relevant legislation. It recognises the related approved code of practice (ACoP), representing best practice and/or guidance from the Health and Safety Executive (HSE) or industry bodies.

This information will be used to develop the hazard management strategies and to inform the development of design principles against which detailed options can be developed and assessed. This approach, including the consideration of all the hazard management strategies for the GDF, will ensure that an appropriate and balanced design is developed. This will be achieved by ensuring legislative compliance, incorporation of relevant best practice and proportionality between the needs of conventional, radiological and environmental safety.

2.3 Learning from experience review

It is recognised that lessons can be learned from recent major construction projects and relevant major incidents within a range of high-hazard industries. A review has been undertaken to recognise the ‘root cause’ of major incidents and the best practice methods employed in other major construction projects. This enables the integration of appropriate design, construction and operational controls into the GDF programme during the development process. The outcome of this review is presented in Section 4.

There are major projects which may be of relevance to the GDF in the future, eg new nuclear build, High Speed Rail Link 2 and the next Crossrail project. Regular ‘learning from experience’ reviews will be conducted throughout the development of the GDF to ensure that all relevant lessons learned are incorporated.

3 Construction and Non-Radiological Safety Assessment

3.1 Health and safety requirements for conventional hazards

This section of the report presents an overview of the high level legislative requirements governing construction and non-radiological health and safety. For each of the CgFSGs, a discussion is presented on the relevant legislation which places requirements on the duty-holder to develop plans to meet their legal obligations. For each CgFSG, reasonably practicable risk reduction measures have been identified as illustrative options that will be considered in the appropriate hazard management strategy and the developing design.

3.1.1 Overarching Health and Safety at Work High Level Requirements

The GDF will be a unique facility within the UK regulatory regime with respect to its function as the long-term disposal facility for radioactive waste. However, with respect to conventional hazards during construction and operation, it shares many features with other similar facilities worldwide and large-scale sub-surface operations. It will also share features with other large-scale construction projects undertaken for high-hazard industries in the UK. These projects are often referred to as operations subject to a ‘permissioning regime’ (eg nuclear, railways, offshore and onshore major hazard industries).

The Health and Safety at Work Act 1974 establishes the general framework within the UK which requires all work activities to be carried out without risk to the health and safety of all persons affected by that work ‘so far as is reasonably practicable’. This is supported by other legislation and guidance that address the regulation of specific industries, activities and hazards.

This section outlines the overarching approach to health and safety at work and good practice for the management of conventional hazards.

Good practice for all industries and hazards [13] essentially incorporates the same overall approach to health and safety at work:

- **plan** – determining policy and planning for implementation
- **do** – profiling health and safety risks, organising for health and safety and implementing the plan
- **check** – measuring performance and investigating accidents and incidents
- **act** – reviewing performance and learning lessons

In addressing these steps, it is the potential for harm or consequences arising from the activity and associated hazards that determine the requirements on the organisation, the workplace and workforce.

This safety integrated approach, to assessing and meeting obligations related to work activities, aims to ensure that the level of defence-in-depth provided against the hazard is based on and proportionate to the assessed risk.

Regardless of the assessed level of risk, in order to ascertain the most appropriate means by which the optimum design solution can be achieved, it is necessary to consider the key principles of safety assessment which include the consideration of the ‘ERICPD’ approach. For the current stage of the design, the key principles which define the hierarchy of controls to be applied are as follows:

- **eliminate** the hazard or not undertaking the hazardous activity, or substitute with something non-hazardous

- **reduce** the inventory of hazardous materials, reduce the energy involved (such as speed or voltage) or substitute with a less hazardous material
- **isolate** the personnel from the hazard, by distance or barriers, either passive (such as an enclosure) or automatic active (for example, local extract ventilation, circuit breakers, guards)
- **control** the extent of exposure by provision of safety systems to detect the hazard, isolate and remove the hazard (such as alarms, trips, interlocks), which may be in combination with work procedures (such as safe systems of work (SSoW), permits to work (PTW))
- **protect** by means of personal protective equipment such as wearing suitable and well-maintained gloves, eye protection and respirators

It is not considered to be appropriate to consider the 'Discipline' (the 'D' in ERICPD) principle at this stage of the project as this is at the lowest end of the risk control hierarchy and should only be considered if all other levels have been considered and deemed unsuitable. Due to the requirements of a generic high level of assessment 'discipline' will only be considered in exceptional cases with appropriate justification. It is recognised that 'discipline' can be of particular relevance during the construction and operational phases and includes the dissemination of safety rules, safety signage, supervision and monitoring for compliance.

For each of the conventional hazards identified, the 'ERICP' hierarchy of control will be considered through the hazard management strategy as the GDF design develops. Examples such as minimising the number of vehicle movements and distances, minimising lift heights, segregation of hazardous substances from the work areas will all be considered. In addition, specific engineering controls and associated operating procedures will be implemented, based upon the assessed risk.

Each industry has established specific best practice and guidance for the management of health and safety, which are reflected in the relevant legislation and captured and presented in associated legislation guidance and/or industry standards and guidance. These are summarised in Appendix A (for relevant legislation) and Appendix B (for relevant good practice). For example:

- Managing Health and Safety in Construction, Construction (Design and Management) Regulations, Guidance on Regulations [14]
- Office of Rail Regulation, Common Safety Method on Risk Evaluation and Assessment [15]
- Guidance for Safer Design of Offshore Installations: An Overview [16]

Guidance is also available for related legislation which, although not directly applicable to the GDF, represents a potential source of relevant good practice. The Mines Regulations 2014 and associated guidance is an example such information.

In each case, the relevant good practice for the management of health and safety considers four main themes; the organisation (including the workforce), the workplace (that is site, facility design and process), risk or hazard assessment of the operations and the resulting controls introduced to manage the risk. For example:

- **Organisation Fundamentals** – the general features needed by any organisation whose work affects safety:

  Defining safety responsibility, organisational goals, establishing a safety culture, ensuring competence and training of workforce, working with suppliers/contractors, communicating safety-related information, co-ordination of work, ensuring continuity of safety management.

- **Process Fundamentals –** methods of working that affect safety:

  Safety planning of all work, systematic processes (such as the RWM design and safety integration process), good design and practice for each activity, configuration management of the facility, maintaining records of the process, design and activities, independent professional review of process.

- **Risk Assessment Fundamentals** – identifying hazards and assessing risk:

  Defining the operations (extent and scope of all activities), identifying hazards associated with the work, assessing risk from these hazards, monitoring risk throughout activities.

- **Risk Control Fundamentals –** controlling risk and showing that it is acceptable:

  Reducing risk to be ALARP by systematic adoption of measures to control the risk, by establishing safety requirements on plant and workforce, evidence of safety (objective evidence that safety requirements are being met), acceptance and approval by internal and external assurance or regulator before activity is undertaken.

Where there is no 'major hazard' involved in the operation or activity, as for most construction projects, the focus is on establishing good practice for the organisation and risk assessment and less emphasis is placed on design/process and engineered risk controls.

The greater the perceived potential for an activity to result in significant harm (in the form of multiple injuries or fatalities), the greater the emphasis in formally demonstrating in the risk assessment (by content and level of detail) that the risk controls for the specific 'major hazard' (for example, fire, explosion and flooding) reduce the risk to a level which is ALARP. For high-hazard industries, the potential consequences are perceived to be so significant that the health and safety arrangements and risk assessment are required to be permissioned by the regulator (independently reviewed) and emergency response arrangements established and exercised.

For the GDF, in order to ensure appropriate health and safety good practice, an integrated approach will be required to the safety management arrangements with radiological, conventional (non-radiological) and environmental hazards being addressed by the design and operation processes. This will address all activities including construction and operations. These arrangements will ensure that, at each stage, hazards are identified and the risks assessed, managed and minimised by appropriate risk controls. The arrangements will be monitored and maintained by suitably qualified and experienced personnel within an appropriate organisation. These arrangements will ensure that during construction and operation all hazards are managed and minimised; and that compliance with the identified relevant primary legislation can be demonstrated.

3.1.2 Conventional Generic Hazard Fault Sequence Groups

The hazard identification process identified a number of standard conventional safety hazards and grouped them into twelve CgFSGs, designated as C1 to C12 namely:

- C1: workplace transport
- C2: working and load at height
- C3: structural collapse
- C4: plant/machinery
- C5: fire and explosion
- C6: projectiles and blast, over-pressure
- C7: airborne hazardous substances and air quality (including asphyxiation)

- C8: flooding
- C9: electrical
- C10: noise and vibration
- C11: concurrent activities (also referred to as ‘conflict hazards’)
- C12: occupational

Appendix C (Tables C1 and C2) presents a summary of the CgFSGs, the associated hazards and the construction and operational activities to which they relate.

3.1.3 On-going Safety Management of Conventional Hazards

At this generic design stage, the current hazard identification studies have identified the construction and operational conventional hazards which present the most significant harm potential for the GDF. The high-level health and safety requirements to address these hazards have been complied with reference to the current relevant primary legislation.

At this early generic phase, it would not be appropriate to develop the specific measures and controls that will be utilised in the GDF programme during construction and operations.

However, sufficient confidence has been gained, that the conventional hazards that could impact on the feasibility of a GDF have all been identified. In addition, through the demonstration of an understanding of the regulatory requirements (that inform the development of the hazard management strategies and design principles), no hazards have been identified that could challenge the feasibility of designing, constructing and operating the GDF. It is considered to be entirely feasible to implement adequate controls and arrangements into the GDF design to either eliminate or manage all potential hazards. Illustrative examples of potential safety measures based on the ERICP hierarchy are presented for each CgFSG.

It is recognised that safety management arrangements to address conventional safety are required for the GDF, with the key requirements that:

- the hazard identification process for construction activities is developed based upon a specific construction PFD
- the methodology for the assessment of construction and conventional hazards will, at the appropriate project phase, need to be formalised in a conventional safety manual as part of the suite of RWM safety case manuals to include construction and operations
- the quantification of the identified hazards will need to be developed in line with the maturation of the GDF design
- the design will need to be developed and optimised, considering the means by which the hazards will be controlled/mitigated, in line with the fundamental principles, including ERICP

Resolution of these issues through FAPs will permit the consideration and comparison of hazards which have the potential to result in conventional, radiological and environmental consequences to be assessed in detail. It is expected that the hazard management strategies, development of detailed design requirements and implementation in the design will ensure these hazards do not warrant further consideration as design basis accidents in the operational phase. This very early consideration of potential conventional hazards will ensure that the GDF design is safe to construct, and that the resulting facility will be safe to operate.

3.2 Conventional fault sequence group safety assessments

3.2.1 Workplace transport hazard (applicable to CgFSG ID C1)

This hazard group encompasses all postulated transport incidents in the workplace involving both construction and operational road or rail vehicles. The group is subdivided into postulated incidents that are as a result of: vehicle on person impact, vehicle on vehicle impact and vehicle on facility impact. These hazards can occur throughout the GDF and during various phases of construction and operation as shown in Appendix C .

During the construction of the GDF, various types of vehicles, excavators and cranes are likely to be used across the whole site, involving the construction of many permanent and temporary structures.

During operations, rail systems or heavy goods vehicles will be used to transport packages around the site and, given the number of package movements per year, this will result in a significant amount of rail and road traffic around the site.

These hazards could result in operators being directly impacted by the vehicles resulting in injury or fatality, or in the vehicles damaging GDF systems such as ventilation, which could also indirectly result in harm. Vehicle accidents could also affect other GDF safety systems, including those performing a nuclear safety function. This is addressed as part of the radiological fault analysis.

The GDF design and operations consider all reasonably practicable steps in line with the ERICP principle, including the following illustrative risk reduction measures:

- **Eliminate:**
    - alternative transport systems such as conveyor systems
- **Reduce:**
    - minimising the potential for vehicle impacts through the design of a safe site layout that includes dedicated areas for specific activities such as vehicle refuelling, parking and maintenance etc.
    - site speed limits
    - use of shunter vehicle for waste package movements
    - park and ride system for operations personnel
- **Isolate:**
    - provision of barriers between the vehicles and pedestrians, suitable traffic routes for the vehicles (see FAP.2016.VOL1.01)
    - include dedicated single purpose routes that avoid mixing of transport activity
    - provision of impact protection to important systems, for example, ventilation, or the placement of these systems away from roadways
- **Control:**
    - appropriate lighting, warning beacons, closed circuit television
    - training, supervision, documented procedures
- **Protection:**
    - vehicles fitted with suitable cabin/roll-cage, driver restraints

3.2.2 Working and load at height hazard (applicable to CgFSG ID C2)

This hazard group includes hazards that arise from working at height and loads held at height. It includes such events as operators falling from ladders, objects dropped during their movement or whilst stored at height. This type of hazard can occur throughout the GDF and during all phases of construction and operation as shown in Appendix C .

These hazards can result in workers being directly injured from falls or dropped loads. Dropped loads could also damage GDF systems which could indirectly result in harm.

As with all significant infrastructure development, during the construction of the GDF it is likely that cranes will be used extensively which will result in a high frequency of lifted loads. There will also be a normal element of construction workers working at height.

During operations there will be a significant requirement to lift: packages, materials and goods. Given the number of movements per year, this will result in a defined set of lifting operations with an associated hazard potential.

The GDF design and operations will consider all reasonably practicable steps in line with the ERICP principle, including the following illustrative risk reduction measures:

- **Eliminate:**
  - use plant, equipment that can be operated or maintained on the ground and maximise activities on the ground, elimination of suspended loads
- **Reduce:**
  - include measures to minimise the maximum fall heights such as nets or lifting height restrictions, limiting lift heights to the minimum required
- **Isolate:**
  - use equipment to prevent falls where work at height cannot be avoided (for example, scaffolding and mobile elevating work platforms), which should be properly maintained and inspected at suitable intervals
  - use lifting equipment where the load being lifted is away from operators
- **Control:**
  - lifting equipment/racking should be suitable (ie, sufficiently strong and stable) for the purpose for which it is used or provided and should be properly maintained and inspected at suitable intervals and visibly marked with any appropriate information (for example, the safe working load)
  - the lifting equipment/load should be positioned or installed to prevent interference by or to other activities and hence minimise/reduce the risk of injury (for example, from the equipment or the load falling or striking operators)
  - maintenance of equipment is restricted to operators who are suitably qualified and experienced to undertake the specific task, including ‘hardware’ measures (such as suitable guards, protection devices, markings and warning devices, emergency stop buttons and personal protective equipment (PPE)) and ‘soft’ procedural measures such as the SSoW (for example, maintenance only when equipment is shut down)
  - use by supervised, trained, competent workers using documented and approved procedures
- **Protection:**
  - harnesses
  - hard hats, safety boots and other appropriate PPE

3.2.3 Structural collapse (applicable to CgFSG ID C3)

This hazard group includes hazards associated with the structural collapse of underground structures such as tunnels and vaults. It includes rockfalls during the underground construction and emplacement phases as shown in Appendix C . Such hazards may occur as a direct result of construction activity, or if there is a failure of the installed structural support, or as a result of an external hazard.

These hazards could result in operators being directly injured or killed due to the collapse of structural features in the underground environment. Structural collapse underground also has the potential to impact surface buildings and operations. Structural collapses could also affect GDF safety systems, including those performing a nuclear safety function. This will be addressed as part of the radiological fault analysis as an internal hazard.

The GDF design and operations will consider all reasonably practicable steps in line with the ERICP principle, including the following illustrative risk reduction measures:

- **Eliminate:**
  - high integrity design process and specification of performance requirements with appropriate margins of safety
- **Reduce:**
  - pre-construction investigation of the ground conditions and feedback to design requirements following characterisation of rock mechanical properties
  - installation of diverse structural support systems such as concrete liner, mesh or rock bolts
- **Isolate:**
  - ensure that construction activities are kept segregated from emplacement operations
  - exclusion of operators from zones during excavation operations
  - ensuring a means of escape is segregated from any areas where there is a risk of structural collapse
  - provide safe zones and emergency support equipment
- **Control:**
  - prevent any part of an excavation or ground adjacent to it from being overloaded by work equipment or material
  - monitoring and surveillance equipment
  - ensuring no material forming the walls or roof of, or adjacent to, the excavation can be dislodged or fall such that a person could be buried or trapped in the excavation
  - ensuring the walls and roof are properly maintained and inspected at suitable intervals and visibly marked with any appropriate information
  - use of most appropriate excavation techniques, such as drill and blast and the use of mechanical excavation techniques including tunnel boring machines or road headers
  - implementation of strict controls on the levels of excavation damage caused to the surrounding rock by controlling the blast design (where applicable, such as electronic delay detonation), implementation of a vibration control and monitoring strategy and careful management of the excavation operations

- regular inspections of underground structures
- **Protection:**
  - hard hats, safety boots and other PPE as appropriate

3.2.4 Plant/machinery hazard (applicable to CgFSG ID C4)

This hazard group encompasses all incidents involving construction or operational plant and machinery in the workplace. Incidents can arise as a result of an operator using the plant or machinery incorrectly, or as a result of equipment failure. This type of hazard can occur throughout the GDF and during all phases of construction and operation as shown in Appendix C . It is envisaged that a significant amount of plant and machinery will be required to support GDF construction and operations presenting a range of hazards.

These hazards could lead to workforce injuries or fatalities, or to damage to other GDF equipment and systems. A FAP has been raised related to ensuring a safe operating envelope for moving plant and machinery (FAP.2016.VOL1.02).

The GDF design and operations will consider all reasonably practicable steps in line with the ERICP principle, including the following illustrative risk reduction measures:

- **Eliminate:**
  - consider alternative plant/machinery that is less hazardous
- **Reduce:**
  - utilise machinery which is appropriate for its intended use, with the minimum energy involved, for example, machinery speed/voltage
- **Isolate:**
  - providing clearance around machinery and minimising operator involvement close to hazardous areas of the machine
  - ensuring safe site layout (such as the provision of barriers between the machinery and normal working areas, pedestrians and vehicle routes)
  - ensuring safe machinery of proven technology which is designed for the activity being undertaken and ‘safeguarding’ (for example, guards, limit switches, interlocks, two-hand controls, light guards, warnings/labelling, alarms and emergency stop buttons)
  - prevent unsafe access or operation which should be properly maintained and inspected at suitable intervals
- **Control:**
  - minimising machinery (with exposed or accessible moving parts) and establish general machinery safety precautions, for example, ensuring that all equipment used is manufactured to meet the Supply of Machinery (Safety) Regulation 2008 and the Provision and Use of Work Equipment Regulations 1998 (PUWER), based on the assessed risk
  - maintenance and inspection in accordance with schedule using competent persons working to documented and approved procedures
  - suitably qualified and experienced machinery operators (for example, suitably supervised, trained, competent) working to written procedures
- **Protect:**
  - hard hats, safety boots, protective gloves and eye protection

3.2.5 Fire and explosion hazard (applicable to CgFSG ID C5)

This hazard group encompasses all fires and explosions in the workplace and can occur anywhere where there is a source of fuel, ignition and oxygen. The explosion and fire risk from naturally-occurring flammable gases such as methane (potentially released from a host rock and overbearing rock during construction), will be addressed as part of this group. Any resulting hazards from blast/over-pressure following an explosion are considered under 'Projectiles and blast, over-pressure hazard (applicable to CgFSG ID C6).

Without adequate controls, fires and explosions can conceivably occur throughout the GDF and during all phases of construction and operation as shown in Appendix C .

During construction, it is envisaged that there may be additional activities which may present an additional fire and explosion hazard, eg welding and hot working.

During operations, the potential for fires and explosions originating from electrical equipment and transport vehicles may present a significant hazard. It should be noted that as the majority of the GDF is underground, the fire and explosion hazard may present specific additional requirements. It is anticipated that more stringent requirement for the underground environment will need to be adopted from relevant good practice, such as the Mines Regulations 2014.

If not protected, operators could be affected by fire from either the direct effect of heat or indirect asphyxiation due to the build-up of combustion gases and the consumption of oxygen. A fire/smoke could also affect other GDF safety systems, including those performing a nuclear safety function such as monitoring and ventilation systems. The nuclear safety impact will be addressed as part of the radiological fault analysis as an internal hazard.

It is also noted that work which involves the storage, use or creation of chemicals, can generate vapours or dusts that can readily burn or create an explosive atmosphere.

The specific fire and explosion hazard associated with flammable gas generation within waste packages is subject to FAP.2016.VOL1.04.

The GDF design and operations will consider all reasonably practicable steps in line with the ERICP principle, including the following illustrative risk reduction measures:

- **Eliminate:**
  - specifying materials that are non-combustible or fire retardant
  - avoiding fuel sources (where practicable)
  - avoiding ignition sources, eg arcing/sparking, welding
  - conducting the activity in a safer environment, eg above ground modular build
- **Reduce:**
  - minimising the potential for fires to occur, for example, vehicle design and minimising fuel levels
  - use of fire resistant materials in cabling, tyres, etc
  - minimising the combustible material loading in any given area
  - minimising rubbish/waste and ensuring good housekeeping and site tidiness and maintaining dedicated emergency routes clear of any combustible material

  - minimising ignition sources from hot work (using Permit to Work (PTW) system), plant and equipment (by correctly sizing electrical and engine driven plant, providing stable mountings for electrical equipment, lighting appropriate for environment; electrical installations, ensuring they are of sufficient capacity for the intended use)
  - preventing all naked flames where practicable
- **Isolate:**
  - isolation through barriers, of combustible materials from potential ignition sources
  - ensuring a means of escape segregated from any areas where there is a risk of fire and/or provisions of 'safe havens' and 'self-rescuers' provisions (where time to escape from the facility could be extensive) (FAP.2016.VOL1.01 and FAP.2016.VOL3.12)
  - fire resistant cubicles for electrical systems and for storage
  - fire barriers/doors/dampers
  - segregation of fire zones to avoid propagation
  - dedicated storage areas (eg for vehicles) with additional fire suppression systems
- **Control:**
  - ventilation systems
  - provision of warning systems (such as dedicated fire and smoke detection and alarm system)
  - provision of fire-fighting apparatus (such as hand held extinguishers, dry risers, vehicle based suppression systems or sprinkler systems)
  - storing of combustible materials, especially volatile materials such as liquefied petroleum gas, segregated from working areas, ideally outside at the surface
- **Protection:**
  - smoke hoods
  - safe havens

3.2.6 Projectiles and blast, over-pressure hazard (applicable to CgFSG ID C6)

This hazard group encompasses projectiles, blast and over-pressure hazards in the workplace as a result of:

- the use of explosives
- disruptive failure of pressure systems or high energy plant (such as high voltage (HV) transformers), and
- detonation of explosive atmospheres

It is assumed, as detailed in the Basis of Operational Assessment [5], that over-pressurisation of waste packages during the operational phase is not possible due to the fact that:

- any in-package processes which have the potential to pressurise the package cannot result in sufficient pressure build-up over the operational phase to challenge package integrity (for example, internal corrosion or chemical reactions)

- relevant waste packages with in-package processes capable of generating a pressurisation hazard, as defined by the Pressure Systems Safety Regulations (PSSR) 2000 and PUWER 1998, will be provided with filtered venting systems

Whilst the use of explosives will only occur during excavation operations, projectiles and blast over-pressure can occur throughout the GDF and during various phases of construction and operation as shown in Appendix C .

During construction, the major hazard will likely be associated with the use of explosives. However, there will also be high energy systems employed to support construction activities (eg power systems and compressed gases). The release of gas from the host rock will also present an ongoing hazard in the construction areas.

During operation, HV transformers, high pressure systems and rotating machinery may present significant hazards within this group.

Disruption and secondary failures could result in operators being harmed from the propagation of the blast/over-pressure and missiles in the form of equipment parts propelled over significant distance (> 100 metres) from the source of the blast. In addition, there is potential for the collapse of secondary structures. The generation of missiles or secondary failures has the potential to give rise to damage to other GDF safety measures including those performing a nuclear safety function. This will be addressed as part of the radiological fault analysis as an internal hazard.

A FAP has been raised related to safe handling and storage of explosives in accordance with codes and standards to minimise the risk of injury or damage to safety systems including calculating safe blast radii and suitable zoning of vulnerable areas to minimise the potential for explosions impinging on waste packages (FAP.2016.VOL1.05). In addition, FAP.2016.VOL1.06 has been raised for design studies to determine appropriate locations for transformers present in the drift to minimise the risk of potential explosion of transformers impinging on vehicles and waste packages in the drift.

The GDF design and operations will consider all reasonably practicable steps in line with the ERICP principle, including the following illustrative risk reduction measures:

- **Eliminate:**
  - specifying materials that are less chemically reactive and combustible (including when damaged, for example, to minimise dust formation)
- **Reduce:**
  - minimising ignition sources from hot work (using PTW system) and plant and electrical installations (ensuring correct atmosphere explosibles (ATEX) rating for the intended environment)
  - preventing all ignition sources in explosive atmosphere areas (for example, naked flames or static/sparks from vehicles)
  - minimising the quantity of explosives, the extent and duration of their storage with particular regard to managing risk from late life failures
  - provision of safe means for discarding or disposing of explosives
  - minimising initiation energy sources
  - equipment / plant design that limits the stored energy
- **Isolate:**
  - storing of explosives segregated from working areas with exposure of personnel requiring access minimised

- storing of explosives on the surface and/or physically and geographically segregated from detonators
- provision of blast/segregation and zoning provisions to ensure fire prevention and prevent explosion propagation
- storing of pressure systems segregated from working areas, ideally outside, for example, compressed air systems and gas cylinders
- ensuring a means of escape, for example, dedicated escape routes segregated from any dangerous substances and explosive atmosphere (DSEA) hazard
- provision of mitigation measures, for example, barriers/doors/dampers segregating DSEA zones, dedicated venting/removal routes for DSEA, PPE
- storing of DSEA materials segregated from working areas and dedicated emergency routes, ideally outside at the surface and segregated, especially corrosive/volatile materials

- **Control:**
  - provision of relief provisions to ensure operation within a safe operating limit, for example, in electrical transformers
  - ventilation systems to remove noxious and/or explosive gases
  - provision of systems which detect hazardous situations
  - systems maintained, inspected and operated in accordance with SSoW
- **Protection:**
  - hard hats and safety boots

It should be noted that, as the majority of the GDF is underground, the explosive atmosphere hazard might present specific additional requirements given that the host rock will provide structures capable of retaining the pressure wave rather than dissipating through failures of structural components. As a result, it will be expected that the more stringent requirement for this environment will need to be adopted from relevant good practice, such as the Mines Regulations, 2014.

3.2.7 Airborne hazardous substances and air quality (applicable to CgFSG ID C7)

Many materials or substances used or created in the workplace are harmful or hazardous. They may be present in solid, liquid or particulate/gaseous form and may be present in anything from paints and cleaners to dust (especially during excavation activities and cement dust during construction), exhaust fumes (especially within enclosed spaces/underground), organic matter or waste. In addition, this includes radionuclides for which the chemotoxic hazards are bounding, such as uranium isotopes (particularly for DNLEU).

This hazard group deals with potential exposure to hazardous substances, both man-made and naturally occurring, which may result in operators being harmed. Harm can occur in the form of: injury or a fatality from immediate toxic poisoning, asthma or other diseases, or serious chronic long-term damage to the body, including cancer. In addition, the build-up of such hazardous substances has the potential to detrimentally impact on air quality, particularly in the underground environment, with resulting adverse effects to workers. A FAP has been raised for studies related to design requirements related to maintenance of air quality in the underground environment (FAP.2016.VOL1.03).

Hazardous substances will be utilised throughout the GDF and during various phases of construction and operation as shown in Appendix C .

The GDF design and operations will consider all reasonably practicable steps in line with the ERICP principle, including the following illustrative risk reduction measures:

- **Eliminate:**
    - use of alternative non-hazardous substances/processes
- **Reduce:**
    - use of alternative less hazardous materials
    - employing plant, materials and activities which minimise fume, dust, gas generation, for example, no dry cement handling
    - employing plant and activities which minimise the need to use and introduce a risk of exposure to hazardous substances, for example, no asbestos
- **Isolate:**
    - segregating sources of fume, dust, gases from normal working areas and escape routes and appropriate warning
    - segregating receipt, handling and storage of hazardous substances from normal working areas and escape routes and appropriate warning
    - isolation of workers from hazards through containment systems and remote handling facilities
- **Control:**
    - effective monitoring for fume, dust, gases to ensure limits within Workplace Exposure Limit (WEL)
    - providing appropriate control measures such as water and moisture and plant or local extract ventilation which should be properly maintained and inspected at suitable intervals
    - effective monitoring for exposure to hazardous substances, for example, demonstrating limits and exposures being demonstrably controlled within defined WEL
    - providing appropriate control measures such as secondary containment to restrict access, plant or local extract ventilation which should be properly maintained and inspected at suitable intervals
    - safe working (suitable supervising, training, information such as Control of Substances Hazardous to Health (COSHH) datasheets) under a SSoW
- **Protection:**
    - additional mitigation measures such as respiratory protective equipment and, if appropriate, health monitoring
    - provision of mitigation measures such as PPE (such as gloves, boots, overalls, safety glasses and respiratory protective equipment), decontamination facilities (for example, wash basins and showers) and, if appropriate, health monitoring

3.2.8 Flooding hazard (applicable to CgFSG ID C8)

This hazard group encompasses anything that can result in the in-leakage of significant volumes (and hence depth) of liquids (such as water) into the workplace. It is particularly relevant to a GDF as gravity will result in liquids collecting in underground ‘sump’ areas. Water can arise from: natural groundwater in the environment, failure of storage tanks/ponds or failure of pipework systems resulting in rapid entry of water into the facility. Flooding can occur as either a slow event or a rapid ingress from something like a rock face collapse.

Flooding hazards can occur throughout the GDF and during various phases of construction and operation as shown in Appendix C .

Flooding hazards may result in operators being directly harmed from immersion or drowning, or may result in damage to GDF systems which can lead indirectly to harm and secondary hazards, eg electrocution. Flooding could also affect GDF safety systems, including those performing a nuclear safety function. This will be addressed as part of the radiological fault analysis as an internal hazard.

The GDF design and operations will consider all reasonably practicable steps in line with the ERICP principle, including the following illustrative risk reduction measures:

- **Eliminate:**
  - eliminate unnecessary water sources, eg grouting of known points of water source ingress
  - eliminate the potential for water ingress from external sources by not sealing areas with large voids to prevent unrevealed accumulation
  - ensure surface points of entry to the GDF are above anticipated surface flooding levels
- **Reduce:**
  - minimise the potential for water ingress from external sources through provision of engineered barriers
  - ensure that all water from construction activities and surface operations is collected and disposed of and not allowed to accumulate
  - provision of liners to reduce areas of high water ingress flow
  - provision of engineered flow paths, gradients and collection and transfer systems
- **Isolate:**
  - provision of appropriate bunding around large fluid storage vessels
  - dedicated pumping systems for removal of flood water
  - flood sources are segregated from working areas and dedicated emergency routes, ideally located outside buildings
  - ensuring a means of escape (dedicated escape routes segregated from any potential flood hazard)
- **Control:**
  - monitoring of in-flows in water
  - provision of warning signs or systems
  - evacuation procedures
- **Protection:**
  - diverse emergency back-up pumping systems

3.2.9 Electrical hazard (applicable to CgFSG ID C9)

This hazard group encompasses all incidents due to operators working with or near electricity and electrical equipment in the workplace, which can occur throughout the GDF and during various phases of construction and operation as shown in Appendix C .

These hazards can result in injury or fatality from electrocution due to electric shock and burns from contact with live parts or arcing from faulty electrical equipment or installations, especially from high voltage systems.

These incidents will also represent a source of ignition for a fire (see 'Fire Hazard') and could result in an explosion (see 'Projectiles and Blast, Over-pressure Hazard').

The GDF design and operations will consider all reasonably practicable steps in line with the ERICP principle, including the following illustrative risk reduction measures:

- **Eliminate:**
  - utilisation of low power systems (where practicable)
  - utilisation of alternative motive force systems such as hydraulic (where practicable)
  - power system design that includes fault detection and protection
- **Reduce:**
  - ensuring electrical power supply, equipment and systems are designed and constructed to an appropriate standard (for example, the Electricity Safety, Quality and Continuity Regulations) and for the proposed usage and operating environment (such as wet conditions, explosive atmospheres)
- **Isolate:**
  - burial of cables on or adjacent to the site (for example, use up-to-date service plans, cable avoidance tools and safe digging practice to avoid danger) which should be isolated but assumed live during construction
  - electrical isolation provision for inactive areas, physical separation, segregation (for example, dedicated cableways and armouring)
  - overhead wires and/or railway or tramway above or adjacent to the site (for example, separating activity from the lines by at least 15 metres of nearest approach of plant/person)
  - if overhead wires are not possible, then stout, distinctive, highly visible barriers to prevent approach, dedicated crossing routes and prevention of access to the area being used for storage
  - If barriers, crossing routes and access prevention are not feasible, the line should be isolated and earthed or re-routed to enable work to proceed
- **Control:**
  - controlled access to HV/current systems (for example, interlocked to prevent access unless power supply isolated)
  - electrical protection (such as fuses, residual-current devices) of each aspect from plant item, socket, supply circuits back to incoming/on-site supply connections
  - ensuring systems are maintained and operated in accordance with written scheme of examination (for example, circuits treated as live although all power supply in area to be isolated before work)
  - provision of appropriate warning and labelling
- **Protection:**
  - worn PPE is not usually adopted against electrical hazards, however insulating protective equipment such as rubber blankets and insulating live-line tools will be considered

3.2.10 Noise and vibration hazard (applicable to CgFSG ID C10)

This hazard group encompasses all incidents due to the harmful effects of noise and vibration in the workplace. Noise and vibration can be transmitted through the airborne pathway or directly via plant or structures. These hazards can occur throughout the GDF and during various phases of construction and operation as shown in Appendix C .

The major noise and vibration hazards will be during excavation/blasting activities. The key hazards can result in operators being injured, especially during excavation activities.

The GDF design and operations will consider all reasonably practicable steps in line with the ERICP principle, including the following illustrative risk reduction measures:

- **Eliminate:**
  - employing plant and activities to eliminate noise hazards and ensuring plant is properly maintained and inspected at suitable intervals
  - employing plant and activities to eliminate vibration hazards and ensuring plant is properly maintained and inspected at suitable intervals
- **Reduce:**
  - providing appropriate control measures such as restricting individual exposure time
  - employing plant and activities to minimise noise hazards
  - employing plant and activities to minimise vibration hazards
  - ensuring plant is properly maintained and inspected at suitable intervals
- **Isolate:**
  - segregating sources of noise from normal working areas and incorporating appropriate warning
  - providing appropriate mitigation measures such as hearing protection zones
  - segregating sources of vibration from normal working areas and appropriate warning
- **Control:**
  - effective monitoring and controlling of noise exposure (for example, demonstrating appropriate response at exposure action value (EAV) and exposure limit value (ELV))
  - effective monitoring and controlling of vibration exposure (for example, demonstrating appropriate response at EAV and ELV)
- **Protection:**
  - use of ear defenders
  - provision of mitigation measures such as ergonomic grips, supports and personal protective equipment

3.2.11 Conflict hazard (applicable to CgFSG ID C11)

The current design assumption is to have concurrent activities at the GDF site. Emplacement operations will be undertaken in parallel with ongoing construction activities but in separate areas of the GDF. This aspect gives rise to potential hazards that are identified as ‘conflict hazards’ in the safety assessment. Parallel activity of this type is necessary to manage the operational phase of the GDF and recognises that not all rock environments are suitable for maintaining open structures over very long periods of time.

Concurrent activities, such as construction of additional facilities whilst the site is operational, can result in operators being injured or a fatality from:

- conflicts between required activities for construction which results in additional hazards to emplacement and operations, and vice versa
- loss of essential services, such as electrical systems, underground ventilation

Whilst conflicts are not a hazard in themselves, they can result in increased exposure of construction and/or operations personnel to hazards resulting from these activities. The conflict hazards could also affect other GDF safety systems, including those performing a nuclear safety function. This is addressed as part of the radiological fault analysis as an internal hazard.

Where concurrent activities result in the need for construction equipment or personnel working and/or travelling through an operational area ('break-in') or vice versa (for example, construction material moved via operations access tunnels) then personnel could be exposed to all hazards associated with that area and vice versa.

The principal control measure for such conflict hazards is to maximise the separation between operational (particularly emplacement) and construction activities, thereby eliminating the potential for conflict for most operations. Thus, the two areas (construction and emplacement operations) will be physically segregated unless in an emergency or for the transfer underground of specific items such as shield doors or crane beams which will normally use the drift.

However, even when the concurrent activities are in separate areas, hazards can still result from the potential interactions. These interactions could include:

- the long range effects of blasting activities on operations, for example, due to vibration affecting plant or dust affecting ventilation systems
- increased site vehicle movements (construction and transport vehicles) affecting construction/operations
- increased risk of dropped load hazards on operational plant during construction activities

The underground layouts for the GDF will be configured to minimise the amount of construction work required up to first waste emplacement. This ensures that the vaults and tunnels are 'new' for the receipt and handling of waste.

The GDF design and operation will consider all reasonably practicable steps in line with the ERICP principle, including the following illustrative risk reduction measures:

- **Eliminate:**
  - identifying all potential hazards posed by coincident/parallel construction and operation activities and de-conflict activities (for example, halt operations, 'make safe' and evacuate operational personnel prior to construction activity)
- **Reduce:**
  - application of blast pattern and rock pillars
  - vault spacing
  - well-practiced construction techniques, such as drill and blast and the use of mechanical excavation techniques including tunnel boring machines or road headers which can be used for construction in all geological environments (such construction techniques have lower impact in terms of vibration than drill and blast methods and hence limit the potential for conflict hazards due to vibration/blasting)

- **Isolate:**
  - ensuring that construction activities are segregated (for example, by airlocks and seals) and do not affect operational areas (for example, commissioning of operational areas)
  - ensuring that the underground infrastructure and support facilities allow the disposal of waste to take place at the same time as ongoing construction, by providing segregation between these activities (such as by utilising airlocks and seals between different zones and areas underground and by the provision of independent ventilation circuits)
  - sequencing of UILW vault construction and disposal will mean that there will be at least one constructed but non-operational vault separating construction and emplacement activities; this separation, by pillars of rock coupled with the design of blast patterns, where required, aims to ensure that blast vibration will not affect the waste emplacement operations
  - provision of a means of escape, for example, dedicated escape routes for construction and operations personnel segregated from any potential hazards
- **Control:**
  - effective management of the interfaces between the conflicting activities will be critical to ensuring the safety of all activities, for example, by ensuring all relevant stakeholders are aware of the conflicting activities and agree to concurrent activities commencing via ‘toolbox talks’, activity boards, permit to work systems, or by putting controls in place to prohibit concurrent activities where no other acceptable controls can be identified
  - specific training of the workforce so that ‘operations’ and ‘construction’ are sufficiently aware of their potential to generate conflict hazards
  - implementation of strict controls on the levels of excavation damage caused to the surrounding rock by controlling the blast design (where applicable, such as electronic delay detonation), implementation of a vibration control and monitoring strategy and careful management of the excavation operations
  - provision of warnings
  - formal hand-over procedures (such as confirmation of plant isolation/ re-establishment)
  - supported by safe working (such as suitable supervision, training, information) under written procedures
- **Protection:**
  - appropriate personal protective equipment will be defined dependent upon the potential conflict hazard identified

3.2.12 Occupational hazards (applicable to CgFSG ID C12)

This hazard group encompasses all incidents which could result in harm to personnel as a result of their occupation within the workplace. This type of hazard can occur throughout the GDF and during the various phases of construction and operation as shown in Appendix C . Many of the hazards discussed in previous sections may be considered occupational hazards, however this section deals with specific hazards such as manual handling and slips and trips.

The conventional occupational hazards have not yet been fully developed for construction and operational activities. However, the key hazards that could result in harm to personnel and, in extreme cases, fatalities have been identified.

The GDF design and operation will consider all reasonably practicable steps in line with the ERICP principle, including the following illustrative risk reduction measures:

- **Eliminate:**
  - use of materials and activities which eliminate the requirement for heavy (for example, > 25 kg) or awkward loads, the distance loads are to be carried or height lifted, or repetitive actions
- **Reduce:**
  - regular cleaning of areas and all accidental spillage/waste rapidly removed
- **Isolate:**
  - provision of barriers around slip and trip hazards
- **Control:**
  - provision of suitable and safe pedestrian walkways and corridors with suitable lighting and good, even conditions underfoot, segregated from potential sources of spillage/contamination
  - supported by safe working (suitable supervision, training, information on occupational hazards)
- **Protection:**
  - provision of mitigation measures such as wrist supports, safety shoes

4 Lessons Learned Review

The approach to health and safety at work is to eliminate or establish barriers between a hazard or risk (such as a flammable substance) and an undesirable event (such as an explosion). Even when these barriers are engineered, there is a dependency on operators implementing and following systems, rules and procedures. Some barriers are remote from the workplace (for example, policies, safety studies) whereas others are close to the workplace (such as equipment, procedures, maintenance activities, operator actions).

Analysis of major incidents in high-hazard industries finds each root cause normally falls into one of four types, with the last type being the most common:

- an event occurs that was either deemed extremely unlikely or unknown/unidentified, such that no risk controls were identified or implemented to manage it
- the impact or severity of an unlikely event that occurs is in excess of that used in the design basis hence beyond the risk control system's capability to manage
- a facility is operated outside its design basis either intentionally or unknowingly
- a combination of individually unimportant errors and/or failures combine to result in a serious outcome

Additionally, the analysis of major incidents in high-hazard industries, with different technical causes and work contexts, has identified several common factors involved when things go wrong. These factors are related to:

- leadership
- attitudes and behaviours
- risk management and
- oversight

RWM is committed to developing and maintaining a safety culture that takes account of learning from experience both from its own project and from other major projects world-wide. The RWM safety culture, together with the associated safety management system, is the basis for ensuring that RWM applies the highest standards of construction and non-radiological safety to all its activities. Table 1 presents a summary of the relevant projects/incidents reviewed and the potential lessons to be learned. RWM will continue its own 'learning from experience' work but will also look to industry and regulatory best practice, both domestic and international, as the programme develops.

Table 1 Lessons Learned Summary

Project / Incident	Lessons Learned Summary
London Olympics 2012 [17, 18]	The key elements that contributed to the development of an effective safety culture on the London Olympic Games site included: • safety being set as a priority and integrated into all the participating companies from the outset through standards and requirements • the clarity throughout the supply chain of the organisational standards and requirements, including the desire for cultural alignment • the empowerment of tier 1 contractors to develop their own processes and systems to deliver the Olympic Delivery Authority's objectives • recognition of the prestige of working on the Olympic Park and striving for excellence in all activities, including health and safety • the scale of the project and the length of the construction phase meant that initiatives had time to 'bed in', and can be tailored to ensure their efficacy and success • belief by workers in the genuine commitment within organisations, as the message was consistent and reiterated across the Olympic Park over time The lessons learned for the GDF are the importance of the role of providing leadership and organisational commitment to ensure good health and safety culture and behaviour via contracts and procurement, communication systems and worker involvement, reinforced via effective risk management, monitoring and assurance.
Crossrail, London 2015 [19, 20]	As a result of fatalities, the Target Zero improvement plan, with its 'five golden rules' of: respect the basics (for example, plan and prepare for your task safely); assess the risk (for example, stop, report and discuss if things change); check the site (such as look out for hazards – don't walk by); follow the site requirements (for example, stick to safe systems of work) and support each other (for example, speak up if you see anything wrong) was implemented. The lessons learned for the GDF are again the importance of providing leadership and organisational commitment to ensure good health and safety culture and behaviour, effective communication and worker involvement, with effective risk monitoring and assurance. In addition, the development of standard methods and good practice guidance for key construction issues developed with and adopted by all contractors involved in the project.

Waste Isolation Pilot Plant (WIPP), United States 2014 [21, 22, 23]	RWM has undertaken a review of the WIPP incidents and has derived the following lessons learnt for the GDF: • **Organisational culture** – being a learning organisation with a strong safety culture. • **Management procedures and oversight** – the importance of capturing requirements, the management system and sufficient independent challenge/oversight. • **Waste acceptance** – ensuring that waste packages are compliant with the safe operating envelope. • **Safety structures, systems and components** – ventilation – capabilities and limitations of engineered systems. • **Maintain design under review** – subject design assumptions/decisions to periodic challenge. • **Maintenance of plant** – understanding, recording and communicating the relationship to safety. • **Modifications to the design** – ensuring that the change control process remains fit for purpose. • **Recovery** – emergency plans and resilience of design.
Gleision Mine Incident, UK 2011 [24, 25]	The immediate cause of this fatal incident was the blasting of the coal face adjacent to an old water-logged working, which allowed the water to breach the remaining coal face and inrush to the working area of the mine. The root cause of this incident was that records for the mine working were not adequate and the decision to blast the coal face had been taken without due regard for the potential for inrush and without any independent oversight or review. The lessons learned element for the GDF is the need to maintain effective risk monitoring and assurance, with the risk assessment and risk controls subject to continuous robust oversight and independent review.
Heathrow Express Tunnel Collapse, London 1994 [26]	On the Heathrow Express site at the Central Terminal Area, jack grouting was employed to rectify building settlements during tunnel construction, using the new Austrian tunnelling methods (NATMs). In the event, the grouting caused a failure in the primary tunnel lining which, in turn, led to the ultimate collapse of both the lining and the building. According to the HSE, a chain of events led directly to the collapse. This included a failure to check sub-standard construction over a period of some three months of grout jacking that damaged the tunnel plus inadequately executed repairs some two months before the collapse. The root cause of this incident was the catalogue of design and management errors identified as “all the hallmarks of an organisational accident”. The collapses could have been prevented, but a cultural mind-set focused attention on the apparent economies and the need for production rather than the particular risks. In addition, safety dependent activities were influenced by contractual relationships with ‘new forms of contract where roles are poorly understood and new technologies where people variously rely on others to understand, communicate and control the risks’. The lessons learned element for the GDF is that “those involved in projects with the potential for major accidents should ensure they have in place the culture, commitment, competence and health and safety management systems to secure the effective control of risk and the safe conclusion of the work.”

Fukushima Nuclear Power Plant, Japan 2011 [27]	The immediate cause of the incident was that the size of the tsunami, following a seismic event, which impacted the site, was greater than the capability of the sea defences (approximately 3 metres greater than the 'design basis event' used for the sea defences). The root causes of this disaster have been extensively reviewed by the whole international nuclear industry and lessons to be learnt established primarily via the specification of 'stress tests' to be applied to nuclear power plant, or in the case of the UK, all permissioned nuclear facilities. The lessons learned for the GDF are that it is necessary to provide defence-in-depth, with not only the facility design catering for the remote external hazards, and potential complete loss of support services but the limit of the design capability assessed and provision made for managing the severe accidents that could result from events beyond the design basis if loss of services occurred over an extended period.
Deepwater Horizon, Gulf of Mexico 2010 [28, 29]	The immediate causes of the incident were established in the BP investigation report as a series of failures: • oil well integrity was not established or lost (that is to say due to poor annulus cementing and failure of the 'shoe track') • hydrocarbons entered the well undetected and well control was lost (that is to say inadequate pressure integrity testing, well pressure control mechanism not maintained, well monitoring ineffective) • hydrocarbon released onto rig ignited (including hydrocarbons diverted to mud-gas separator with gas vented onto rig, fire and gas detection system failed to prevent ignition) • blowout preventer did not seal well (such that the emergency operation was not effective) As noted in more recent industry led assessment of this incident, the technical complexity of the operation being undertaken was a contributing factor to its cause and the subsequent ineffective emergency response to the on-going oil spill. However, the root cause was a lack of a strong safety culture and robust independent scrutiny, such that there was a focus on speed over safety – most decisions were made in favour of approaches which were shorter in time and lower in cost. Hence, there was a lack of configuration change management and accumulation of risks due to wider management failings. For example, the process safety controls on safety critical operations were not maintained to the highest standard; senior managers did not apply effective control; effective auditing systems were not in place; poor communications between contractors; lack of engineering expertise on site; and failure to implement management of change processes. The lessons learned for the GDF are ensuring there is a strong organisation with a strong safety culture, associated management procedures and oversight, with clear understanding of the process safe operating envelope, where the risk controls functional requirements are based on comprehensive risk assessment, and the risk controls are maintained, any modification of the plant design is controlled, and there exists emergency preparedness to address all worst case scenarios.

Buncefield, UK 2011 [30]	The underlying causes of the explosion and fire at the Buncefield oil storage depot were that a tank being filled with petrol was overfilled, the petrol overflowed through vents at the top and formed a vapour cloud near ground level, which ignited and exploded. The tank was overfilled as it was being 'filled blind' with petrol as the manual gauge was stuck and the independent automatic shut-off switch was inoperative. The investigation also found the secondary (retaining wall) and tertiary (drains and catchment area) containment were inadequately designed and poorly maintained. The root causes were found by the investigation to be that there was a lack of configuration change management and an accumulation of risks (overall throughput had increased) due to wider management failings. For example, the process safety controls on safety critical operations were not maintained to the highest standard; senior managers did not apply effective control; effective auditing systems were not in place; poor communications at shift handover; lack of engineering expertise on site; and failure to implement management of change processes. The lessons learned for the GDF are similar to those previously identified under the WIPP incident, of ensuring there is a strong organisation with a strong safety culture. This safety culture will be reflected in the associated management procedures and oversight. There will be a clear understanding of the process safe operating envelope; the risk controls' functional requirements will be based on comprehensive risk assessment; the risk controls will be maintained and any modification of the plant design will be controlled. There will be emergency preparedness in place to address all scenarios, including worst case scenarios.

The construction and non-radiological hazards from the above reviewed incidents have all been considered in developing this generic safety assessment for the GDF, such as fire, tunnel collapse, release of hazardous/flammable substances. The means of preventing/controlling these hazards have been identified at a high level and will be considered within the GDF design as it develops through the RWM design development process.

5 Impact of Different Host Geological Environments

It is noted that different host rocks and the surrounding geological environments give rise to differences in the likelihood and severity of conventional hazards resulting from the construction and operation of the GDF. In addition, very different construction techniques will be used for the different host rock types.

This section considers the impact of different host rocks and excavation techniques on the types and extent of conventional hazards presented and the applicable legislation.

- **Higher strength rock**

  The potential for natural radon gas (classed as a radiological hazard) to be present is greater for a higher strength host rock. In addition, this rock type includes significant amounts of silica which increase the airborne dust hazard generated during excavation, thereby increasing the potential source of accumulation of airborne chemotoxic hazards (concentration potentially exceeding WEL) which will require management through suitable ventilation plant.

- **Lower strength sedimentary rock**

  The potential for methane to be present is greater in lower strength sedimentary rock environments as a result of methane hydrates which migrate through geological faults and accumulate, increasing the potential source of chemotoxic hazards and the risk of explosions.

- **Evaporite rock**

  Evaporites (salts) are soluble in water, hence such host rocks are a potential source of pollution and the dust generated by their excavation by any means represents an increased source of airborne dust hazard. This also means spoil is a potential contaminant and limits the long-term surface storage of spoil. There is also a likely need for an increased level of transport movements associated with the evaporite rock as the spoil will need specific storage / disposal considerations.

  For some evaporite rock, there is increased potential for spalling and falling debris from expected failure of support systems or creep of rock strata in tunnels and shafts. On-going ‘ground control’ is likely to be a key activity in the evaporite environments found in the UK.

  In addition to the above, as a result of creep there is potential for onset blockage of ventilation shafts, or a change in the dimensions of the transfer tunnels (for example), which may restrict access. Regular inspections and maintenance will be required to ensure that access ways remain safe and functional.

  For evaporite rock, the use of a shaft and the associated means of moving equipment and personnel to the underground areas carries an alternative risk relative to the use of a drift in the other rock types.

- **Drill and blast**

  Drill and blast techniques may be used for vertical access shafts for all host geological environments and for the access drift, tunnel complex, vault/disposal area.

  Drill and blast excavation techniques involve the use of explosives, and hence there is an increased potential source of projectiles and blast, over-pressure hazard coupled with noise and vibration hazards. In addition, there will be an increased potential fire hazard and, with the drilling fluids used, the resultant explosive fumes will be a potential source of release of chemotoxic hazards. The resulting dust from the blast also represents a source of airborne dust hazard.

Drill and blast techniques create an exposed area at the rock face, and a period when it is unsupported. This will require rock support systems in order to reduce the risk.

The increased noise and vibration hazard from the drill and blast technique is of particular significance when considering conflict hazards to operations.

However it is noted that drill and blast techniques are well established and continue to be safely employed on a global basis in the underground environment.

- **Tunnel boring machine**

  Tunnel boring machine (TBM) techniques are expected to be the primary excavation method for the access drift, tunnel complex and vault/disposal area for lower strength sedimentary rock. It could also be used for the access drift for a higher strength rock.

  The use of TBMs can create hazards as a result of heat generating rotating machinery, though typically the TBM will have manual/automatic fire suppression systems together with limited flammable inventories. The dust generated by the TBM also represents a potential source of airborne dust hazard. However, this means of tunnelling is a proven and well-tested technique which includes controlled spoil systems and an in-built rock support liner.

  TBMs generally offer a more stable, better finished, and more enduring excavation, because there are less stresses and disturbances passed on to the surrounding rock (ie TBMs can result in a smaller engineering damage zone (EDZ) when compared to other methods). In addition, they provide some level of support to the rock face during excavation, hence a reduced potential for rockfall and falling debris.

- **Continuous miner**

  Continuous miner or other mechanical excavation techniques are expected to be the primary excavation method for the tunnel complex, vault /disposal area for evaporite rock. It can also be used for these aspects for a lower strength sedimentary rock, but has not typically been employed for a higher strength rock.

  The use of mechanical excavation techniques can create hazards as a result of heat generating rotating machinery but with limited flammable inventories. The dust generated by the mechanical excavation techniques also represents a potential source of airborne dust hazard. In addition, the nature of the excavation technique, introduces a potential risk of gross water inflow during cutting operations through the water table (if present at the selected site). However, this means of tunnelling is a proven and well tested and such issues are routinely managed in projects implementing this technique.

For whichever host geological environment in which the GDF may be located, deviations in rock type can be expected, such as water bearing strata, running sands and gravel, weaker rock mass, or the discovery of significant geological features during underground construction.

It should be noted that, while this section emphasises the hazards and relative differences specific to each host rock type and construction technique, all are well understood and manageable, thereby providing confidence that these issues can be resolved to ensure safety. In addition, there are no significant differences in the number of construction personnel or the number of vehicles required to conduct the different construction techniques. Nor is it anticipated that there will be any major differences in the spoil recovery operations between the use of TBM and drill and blast. Spoil (as waste) will consist of dust/slurry and retrieval will usually be via a conveyor system or via a track, if already sited.

As an illustrative comparator, the maximum quantity of spoil calculated over the lifetime of the GDF is in the order of 6.5 to 11 Mm^3 (ie total spoil volume) whereas for a planned new potash mine in the UK, the quantity of mined product is likely to be in the order of 22 Mm^3y^{-1}

(ie product per year). This comparison shows that the GDF spoil generation is relatively modest in comparison with some underground projects such as commercial mines.

Global developments in 'mining technology' are being monitored by RWM and once actual sites and geological ground conditions become clear, the appropriate excavation methods will be selected as part of the final concept. This Safety Case demonstrates that, irrespective of any future developments, proven excavation methods already exist for the environments under consideration.

6 Implementation

This safety assessment has identified, at a generic level, the construction and operational conventional hazards associated with the GDF. For the current generic stage the high level health and safety requirements and relevant primary legislation, to address the most significant conventional hazards, have been identified. For each hazard, a suitable hazard management strategy will be developed and implemented as the GDF design is developed.

This assessment has identified a number of FAPs to ensure a comprehensive approach to conventional safety is defined for the GDF. The highest priority FAPs to address identified conventional safety issues (FAIs) are presented in Table 2. RWM's intent is that as safety management arrangements are developed, consideration of conventional hazards will be fully integrated into the future GDF design and safety process. This will ensure that conventional hazards are considered throughout the development process and proportionate levels of controls and arrangements established which complement those incorporated for radiological safety.

Table 2 FAP Listing

FAP ID	FAP Description
FAP.2016.VOL1.01	Undertake a study to optimise the design to ensure that the risk to operators and other on-site workers as a result of vehicle accidents are minimised including the provision of safe access and egress routes.
FAP.2016.VOL1.02	Undertake a study to determine what engineering or administrative measures are required to ensure a safe operating envelope to minimise the risk from hazards related to moving plant.
FAP.2016.VOL1.03	Undertake a study to determine design requirement related to air quality in the subsurface environment to minimise the risk of airborne hazards to operators.
FAP.2016.VOL1.04	Undertake a study to determine the requirements for waste package specifications to include thresholds for flammable or explosive gas build up to minimise the risk of potential injury following deflagration or conflagration of an explosive atmosphere.
FAP.2016.VOL1.05	Undertake a study to ensure a safe blast radius is defined to minimise the risk of potential for explosions impinging on packages.
FAP.2016.VOL1.06	Undertake a study to determine appropriate locations for transformers present in the drift to minimise the risk of potential explosion of transformers impinging on vehicles in drift.

7 Conclusions

The extent to which the principal claim (OSC.SC1) has been demonstrated is summarised below.

This 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 risk of injury due to conventional hazards.

This volume, the construction and non-radiological safety assessment, addresses conventional safety hazards for the GDF at a generic level. It excludes the assessment of radiological and environmental consequences associated with construction and operation of the GDF. The safety assessment is illustrative; it is applicable to a feasibility study stage where the hazards considered to provide the greatest harm potential have been identified.

The aim of this safety assessment report is to provide confidence that all reasonably practicable steps can and will be taken to implement design provisions whose function is to prevent or minimise the risk of injury due to conventional hazards. In order to provide evidence for this claim, RWM has demonstrated an understanding of the potential construction and non-radiological hazards such that no significant feasibility obstacles have been identified. Future site specific assessments will be where claims of compliance against targets, tolerability of risks and the ALARP principle are made. This report demonstrates that:

- Hazard identification studies have been undertaken for appropriate aspects of the construction and operation of the GDF to identify conventional hazards.
- The hazards identified have been grouped into conventional generic fault sequence groups.
- The legislative controls, which specify the minimum requirements for managing these hazards safely, have been identified. In addition, relevant good practice from within the nuclear industry and more general industrial practices, including surface and sub-surface civil engineering and construction and operations in a sub-surface environment, have also been identified.
- The construction and non-radiological safety assessment will provide the basis for the hazard management strategy, including design principles, which will be applied to the developing design for each of the hazards.
- Relevant incidents and recent projects have been reviewed and lessons to be learnt identified.
- The issues arising from concurrent activities at the GDF site and the impact of different host rocks relative to conventional hazards have been reviewed.
- The safety management arrangements and relevant good practice to manage conventional hazards safely are recognised as being essential to ensure the safety of persons and construction and operations, and will be embedded into the GDF design process as it evolves.

The safety assessment concludes that the following conventional fault groups are the most significant in terms of potential for harm during the construction phase:

- structural collapses underground including rockfalls
- fire and explosions (particularly in the underground environment)

- flooding (particularly in the underground environment)
- transport accidents
- air quality underground

It is expected that the hazard management strategies, development of detailed design requirements (and implementation in the design) will ensure these hazards do not warrant further consideration as design basis accidents in the operational phase. If it is safe to construct, the nature of the design will ensure it is safe to operate. The design development and means of ensuring through life delivery will be an integral part of the GDF programme.

In summary, whilst it is not possible at the current generic stage of the GDF project to identify specific safety functions, sufficient confidence has been gained that the conventional hazards have been identified and understood. Sufficient and adequate controls and arrangements are considered to be feasible and can be incorporated into the GDF design. It is acknowledged that the design will need to be developed in order to undertake option studies and optimisation. This includes the requirement to ensure that the GDF design incorporates the appropriate balance between the radiological, non-radiological and environmental hazards. This will be further considered as part of the design development through the hazard management strategy.

Further work has been identified (FAPs) to develop the safety management arrangements and to ensure that conventional hazards are considered throughout the GDF design process. The areas which require further work to fully underpin the principal claim are largely related to actual detailed design development that will take place at the site specific stage.

The analysis of a broad range of industrial incidents has demonstrated the importance of developing and maintaining a strong safety culture. A strong safety culture underpinned by a comprehensive safety management system will ensure that safety is given the highest priority and visibility. The safety management system ensures that RWM processes and procedures are aligned to keep safety as a core aspect of normal RWM business. RWM's corporate safety culture is being supported and developed through initiatives such as 'see something say something', near-miss reporting, importance of day to day safety and the monitoring aspects such as staff surveys, safety performance indicators in each monthly management report.

RWM is committed to building on this good practice as the organisation moves forward as a prospective nuclear site licence company under the *Nuclear Installations Act 1965 (as amended).* In developing its safety culture RWM will take account of learning from experience both from the GDF programme and from other major projects worldwide. The safety culture, together with the associated safety management system, will be the basis for ensuring that RWM applies the highest standards of construction and conventional safety in the context of a GDF.

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: Generic Operational Safety Assessment, Volume 3: Accident Safety Assessment*, DSSC/313/01, 2016.

5 Radioactive Waste Management, *Geological Disposal: Basis of Operational Assessment*, 2016 (unpublished).

6 Radioactive Waste Management, G*eological Disposal: Generic Disposal Facility Designs*, DSSC/412/01, 2016.

7 Radioactive Waste Management, *Geological Disposal: Generic Environmental Safety Case – Main Report*, DSSC/203/01, 2016.

8 Radioactive Waste Management, *Geological Disposal: Generic Transport Safety Case – Main Report*, DSSC/201/01, 2016.

9 Radioactive Waste Management, *Geological Disposal: Generic Operational Safety Case – Main Report*, DSSC/202/01, 2016.

10 Radioactive Waste Management, *Geological Disposal: Volume 4: Criticality Safety Assessment*, DSSC/314/01, 2016.

11 Radioactive Waste Management, *Geological Disposal: Volume 2: Normal Operations Safety Assessment*, DSSC/314/01, 2016.

12 Radioactive Waste Management, *Engineering Design Manual*, RWM120, Rev 1, 2016 (unpublished).

13 Health and Safety Executive, *Managing for Health and Safety*, HSG-65, Rev 3, ISBN 978-0-7176-6456-6, 2013.

14 Health and Safety Executive, *Managing Health and Safety in Construction, Construction (Design and Management) Regulations, Guidance on Regulations*, Series L153, 2015.

15 Office of Rail Regulation, Common Safety Method for Risk Evaluation and Assessment, Guidance on the Application of Commission Regulation (EU) 402/2013, Issue 1, 2015.

16 Energy Institute, *Guidance for Safer Design of Offshore Installations: An Overview*, 2005.

17 Health and Safety Executive, *Safety Culture on the Olympic Park*, Research Report No. RR942, 2012.

18 Health and Safety Executive, *Pre-conditioning for Success, Characteristics and Factors Ensuring a Safe Build for the Olympic Park*, Research Report No. RR955, 2012.

19 Crossrail, *Health and Safety Annual Report 2015*, CR-XRL-Z7-RGN-CR001-50043, 2015.

20 Crossrail, *Healthy By Design, A Guide for Crossrail Design Teams*, CR-XRL-Z7-XCS-CR001-00002 Version 3, 2015.

21 US Department of Energy, *Accident Investigation Report: Underground Salt Haul Truck Fire at the Waste Isolation Pilot Plant February 5, 2014*, 2014.

22 US Department of Energy, *Accident Investigation Report: Phase 2 – Radiological Release Event at the Waste Isolation Pilot Plant February 14, 2014*, 2015.

23 Radioactive Waste Management, *Learning from Experience: An Assessment of the Implications of February 2014 Incidents at WIPP, On the Implementation of Geological Disposal in the UK*, Issue 1.3, LL24267075, 2015.

24 Health and Safety Executive, *Gleision Mine Incident, 15 September 2011, A Factual Report by the HSE*, 2015.

25 The Mines (Precautions Against Inrushes) Regulations 1979, Statutory Instruments 1979, No. 318, 1979.

26 Health and Safety Executive, *Collapse of NATM tunnels at Heathrow Airport. A Report on the Investigation by the Health and Safety Executive into the Collapse of NATM Tunnels at the Central Terminal Area of Heathrow Airport on 20/21 October 1994*, 2000.

27 Office for Nuclear Regulation, *"Stress Tests" for UK Non-Power Generating Nuclear Facilities, Final Report*, 2012.

28 BP, Deepwater Horizon - Accident Investigation Report, 2010.

29 Deepwater Horizon Study Group, *Final Report on the Investigation of the Macondo Well Blowout*, 2011.

30 Published by the Health and Safety Executive on behalf of the Competent Authority for the Control of Major Accident Hazards HSE, *Buncefield: Why Did it Happen? The Underlying Causes of the Explosion and Fire at the Buncefield Oil Storage Depot, Hemel Hempstead, Hertfordshire on 11 December 2005*, 2011.

Glossary

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

Appendix A – Current Key Legislation

This appendix presents a summary of each of the key legislation identified as being directly relevant to the GDF project. This is presented in the following table.

Table A1 Legislation summary

Primary Health and Safety Legislation (and Guidance if Available) as of late 2015		Legislation Summary
Reference	**Title**	
MHSWR 1999	*Management of Health and Safety at Work Regulations 1999* See also *Managing for Health and Safety (HSG65)*, Third Edition, 2013.	These set out some broad general duties which apply to almost all kinds of works. They are aimed at improving health and safety management. The employer is required to assess the risk to health and safety of their employees and to anyone else who might be affected by their work activity. This is necessary to ensure that preventative and protective steps can be identified to reduce or control the hazard in the workplace. There is also the need to establish emergency procedures, health surveillance and provide information and training.
WHSWR 1992	*Workplace (Health, Safety and Welfare) Regulations (WHSWR) 1992* *Approved Code of Practice and Guidance (L24)*, Second Edition, 2013	The employer has an obligation to reduce risks associated with work in and near buildings. This includes ensuring the workplace is in a good state of repair (maintenance) and discusses a wide range of topics and requirements on sufficient ventilation, temperature and lighting, adequate workspace allocation, safeguards provided against falling or being struck by a falling object, sanitary and washing facilities provided (for example, rest rooms and change rooms) and a drinking water supply.

Primary Health and Safety Legislation (and Guidance if Available) as of late 2015		Legislation Summary
Reference	**Title**	
CDM 2015	*Construction (Design and Management) (CDM) Regulations 2015* *Guidance on Regulations (L153)*, 2015 See also *Health and Safety in Construction (HSG150)*, Third Edition, 2006	These regulations impose health and safety requirements with respect to construction activities applicable to all those involved regardless of role. The key elements are: (a) managing the risks by applying the general principles of prevention (b) appointing the right people and organisations at the right time (c) making sure everyone has the information, instruction, training and supervision they need to carry out their jobs in a way that secures health and safety (d) duty holders cooperating and communicating with each other and coordinating their work and (e) consulting with workers and engaging with them to promote and develop effective measures to secure health, safety and welfare.

Primary Health and Safety Legislation (and Guidance if Available) as of late 2015		Legislation Summary
Reference	**Title**	
FSO 2005	*Regulatory Reform (Fire Safety) Order 2005 (FSO)* See also *Regulatory Reform (Fire Safety) Order 2005: A Short Guide to Making Your Premises Safe From Fire*, DCLG, 2006	This order replaces most of the previous fire safety legislation. It places a requirement on any person who has some level of control in non-domestic premises to take reasonable steps to reduce the risk from fire and make sure people can safely escape if there is a fire. The key requirements are to: • carry out a fire-risk assessment identifying any possible dangers and risks • consider who may be especially at risk • get rid of or reduce the risk from fire as far as is reasonably possible and provide general fire precautions to deal with any possible risk left • take other measures to make sure there is protection if flammable or explosive materials are used or stored • create a plan to deal with any emergency and, in most cases, keep a record of your findings • provide staff information, fire safety instruction and training • review your risk assessment and findings regularly
LOLER 1998	*Lifting Operations and Lifting Equipment Regulations (LOLER) 1998* *Approved Code of Practice and Guidance (L113)*, Second Edition, 2014; See also *Lifting Equipment at Work, A Brief Guide (INDG290)*, Revision 1, 2013	These regulations impose health and safety requirements with respect to lifting equipment (as defined within the regulations). They are not industry specific and apply to almost all lifting operations. Provision is made within the regulations including the strength and stability of the lifting equipment; the safety of the equipment for lifting personnel, installation and positioning of the equipment; the marking of the equipment (that is to say load limits); the organisation of the lifting operations; the examination and inspection of the equipment.

Primary Health and Safety Legislation (and Guidance if Available) as of late 2015		Legislation Summary
Reference	**Title**	
PUWER 1998	*Provision and Use of Work Equipment Regulations (PUWER) 1998* *Approved Code of Practice and Guidance (L22)*, Fourth Edition, 2014; See also *Providing and Using Work Equipment Safely, A Brief Guide (INDG291)*, Revision 1, 2013	These regulations impose health and safety requirements with respect to the provision and use of work equipment, which is defined as 'any machinery, appliance, apparatus, tool or installation for use at work (whether exclusively or not)'. This includes ensuring that the equipment is fit for its intended purpose, is regularly maintained, that the persons using the equipment are suitably trained. Exposure to hazards must be minimised using control systems, guards and trip devices, and PPE (as a last resort) where appropriate.
MHOR 1992	*Manual Handling Operations Regulations 1992 (as amended) (MHOR)* *Guidance on Regulations (L23)*, Third Edition 2004; See also *Manual Handling at Work, A Brief Guide (INDG143)*, Revision 3, 2012	The objective of these regulations is to apply an ergonomic approach to the prevention of injury while carrying out manual handling tasks. This applies to all lifting, loading, pulling, pushing and carrying operations. Manual handling operations must be avoided where practical (for example, using mechanical alternatives) and, where this is not possible, the task must be evaluated and assessed to reduce the risk of injury to the employee. Appropriate training must be given.
WAHR 2005	*Work at Height Regulations (WAHR) 2005* See also *Working at Height, A Brief Guide (INDG401)*, Revision 2, 2014	Employers have a duty to control health and safety risks to their employees from exposure to working at height. The employer must ensure that risk assessments are undertaken and risks are eliminated or, where elimination is not reasonably practicable, controls are introduced to reduce the risk from working at height to as low a level as is reasonably practicable. Any work at height activity must be properly planned, supervised and carried out by competent people. Suitable information, instruction and training must be provided.

Primary Health and Safety Legislation (and Guidance if Available) as of late 2015		Legislation Summary
Reference	**Title**	
Vibration Regs 2005	*Control of Vibration at Work Regulations 2005* *Guidance on Regulations – Hand Arm Vibration (L140)*, First Edition, 2005; See also *Hand-Arm Vibration at Work, A Brief Guide (INDG175)*, Revision 3, 2012 *Control Back-Pain Risks From Whole-Body Vibration (INDG242)*, Revision 1, 2005	Employers have a duty to control health risks to their employees from exposure to whole-body and hand-arm vibration. The regulations define action values and limit values for daily exposure to vibration. The employer must ensure that risk assessments are undertaken and risks are eliminated or, where elimination is not reasonably practicable, controls are introduced to reduce the exposure to vibration to as low a level as is reasonably practicable. Suitable information, instruction and training must be provided.
Noise Regs 2005	Control of Noise at Work Regulations 2005 – Guidance on Regulations (L108), Second Edition, 2005; See also Noise at Work A Brief Guide to Controlling the Risks (INDG362), Revision 2, 2012	The employer must control exposure to noise by carrying out noise assessments which must identify employees who are likely to be exposed to noise at or above defined EAVs, and identify the appropriate action to be taken. Where elimination is not possible, the employer must reduce the risks down to as low as is reasonably practicable by introducing control measures to reduce the noise. Appropriate PPE (as last resort) and warning information must be provided.
Confined Space Regs 1997	*Confined Spaces Regulations 1997 – Approved Code of Practice, Regulations and Guidance (L101)*, Third Edition, 2014	A confined space is a place which is substantially enclosed (though not always entirely), and where serious injury can occur from hazardous substances or conditions within the space or nearby (for example, lack of oxygen). The employer must ensure that risk assessments are undertaken and risks are eliminated or, where elimination is not reasonably practicable, controls are introduced to reduce the risk from working in a confined space to as low a level as is reasonably practicable. Any working in a confined space must be properly planned, supervised and carried out by competent people. Suitable information, instruction and training must be provided.

Primary Health and Safety Legislation (and Guidance if Available) as of late 2015		Legislation Summary
Reference	**Title**	
PPER 2002 & PPEWR 1992 amd	*Personal Protective Equipment Regulations (PPER) 2002 and the Personal Protective Equipment at Work Regulations (PPEWR) 1992 (as amended)* *Guidance on Regulations (L25)*, First Edition, 2005; See also *Personal Protective Equipment (PPE) at Work. A Brief Guide (INDG174)*, Revision 2, 2013.	The employer must provide suitable PPE to any employee who may be exposed to any risk while at work. PPE must be used as a last resort, and must be assessed to ensure that it is suitable. PPE must be regularly maintained and replaced when appropriate. Employees must be provided with instructions on how to use it safely and correctly.
DSEAR 2002 & ATEX 2014	*Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) 2002 & Atmosphere Explosibles (ATEX) Directive 2014/34/EU* *DSEAR Approved Code of Practice and Guidance on Regulation (L138)*, Second Edition, 2013; See also *A Brief Guide to the Dangerous Substances and Explosive Atmospheres Regulations (INDG370)*, Revision 1, 2013.	These regulations aim to protect against risks from fire and explosion related to dangerous substances and potentially explosive atmospheres or from gases under pressure and substances corrosive to metals that are present in the workplace. Dangerous substances are any substances or preparations that, due to their properties or the way in which they are being used, could cause harm to people from fires and explosions. They may include petrol, liquid petroleum gases, paints, varnishes, solvents and dusts. DSEAR require that any workplaces where explosive atmospheres may occur are classified into hazardous zones based on the risk of an explosion occurring, and protected from sources of ignition by selecting equipment and protective systems on the basis of the categories set out in the Equipment and Protective Systems for Use in Potentially Explosive Atmospheres Regulations (EPS), as specified under ATEX. A risk assessment must be conducted of work activities involving dangerous substances, and measures provided to eliminate or reduce the risks by introducing control measures. Equipment must be provided to deal with emergencies, and adequate information and training provided.

Primary Health and Safety Legislation (and Guidance if Available) as of late 2015		Legislation Summary
Reference	**Title**	
ER 2014	*Explosives Regulations (ER) 2014 Guidance on Regulations – Safety Provisions (L150)*, First Edition, 2015	These regulations place duties on employers, private individuals and other people manufacturing explosives, storing larger quantities of explosives or storing explosives that present higher hazards or greater risks of initiation. They consolidate and replace previous legislation, including certification. The following principles should be followed: • people undertaking explosives operations should be competent to carry out their particular roles • the particular hazards associated with the explosives should be understood • the sources of energy that could cause the explosives to initiate should be identified • appropriate safety measures should be part of a planned and proportionate system of work to control all sources of energy that could cause an initiation • particular care should be taken where an activity involves the application of energy to an explosive to ensure that this is controlled • so far as is reasonably practicable, the quantity of explosives, extent and duration of exposure to the hazard should be minimised • the number of people exposed to the hazard should be limited to the minimum necessary for the activity in hand • precautions should be in place to prevent an explosives event from escalating if an initiation does take place • precautions should be in place to protect people if an initiation does occur • robust systems should be in place to make sure that the necessary precautions are in place and remain effective

Primary Health and Safety Legislation (and Guidance if Available) as of late 2015		Legislation Summary
Reference	**Title**	
PED & PER 1999	*Pressure Equipment Directive (Directive 97/23/EC) (PED), Pressure Equipment Regulations 1999 (PER)*	These regulations are associated with the design, manufacture and supply of pressure systems to be used in the workplace. They apply to equipment and assemblies of pressure equipment with a maximum allowable pressure >0.5 bar. They specify the essential safety requirements (ESR) that qualifying vessels must satisfy. Additionally, there are details of how the different products are classified, the technical requirements that must be satisfied, and the conformity assessment procedures that must be followed.
PSSR 2000	*Pressure Systems Safety Regulations (PSSR) 2000 – Approved Code of Practice and Guidance on Regulations (L122)*, Second Edition, 2015; See also *Pressure Systems A Brief Guide to Safety (INDG261)*, Revision 2, 2012	These regulations aim to protect against risks from the safe operation of a pressure system present in the workplace. The duty holder must: • provide safe and suitable equipment • know the operating conditions • fit suitable protective devices and ensure they function properly • carry out suitable maintenance; • make provision for appropriate training • have the equipment examined (written scheme of examination) • choose a competent person

Primary Health and Safety Legislation (and Guidance if Available) as of late 2015		Legislation Summary
Reference	**Title**	
EAWR 1989 & BS7671: 2008	*Electricity at Work Regulations (EAWR) 1989* & *BS7671: 2008 Requirements for Electrical Installations (or IET Wiring Regulations) – Guidance on Regulations (HSR25)*, Third Edition, 2015 *Electricity at Work: Safe Working Practices (HSG85)*, Third Edition, 2013; See also *Electrical Safety and You A Brief Guide (INDG231)*, Revision 1, 2012; *Electrical Safety in Mines (HSG278)*, First Edition, 2015	These regulations introduce a control framework for incorporating fundamental principles of electrical safety, applying to a wide range of plant, system and work activities. They apply to all places of work and electrical systems of all voltages. The employer is required to assess the risk from the use of electricity to their employees and to anyone else who might be affected by their work activity. All reasonably practicable preventative and protective steps should be taken to reduce and control the hazard in the workplace, including use of competent persons, and information and training should be provided.
ESGCR 2002	*Electricity Safety, Quality and Continuity Regulations (ESGCR) 2002 – Guidance (URN 02/1544)*, DIT, 2002	These regulations relate to the generation and distribution of electricity via the UK National Grid, specify safety standards to protect the general public and consumers from danger, along with specifying power quality and supply continuity requirements to ensure an efficient and economic electricity supply. These are in addition to the requirement of EAWR 1989.

Primary Health and Safety Legislation (and Guidance if Available) as of late 2015		Legislation Summary
Reference	**Title**	
COMAH 2015	*Control of Major Accident Hazards Regulations (COMAH) 2015 – Guidance on Regulations (L111)*, Third Edition, 2015.	These regulations aim to prevent major accidents and, should one happen, require businesses to limit the effects on people and the environment. The guidance defines the quantities of flammable, environmentally hazardous or toxic substances on site that have a major accident hazard potential, which has the capability to cause multiple injuries or fatalities to those working on site or living in the local community and/or cause damage to the environment. All COMAH sites must: • notify the competent authorities (CA) • obtain from them consent for the hazardous substances • prepare a major accident prevention policy (MAPP) taking all reasonably practicable measures necessary Top tier COMAH sites must also: • submit a formal COMAH safety report to the CA • prepare and test an on-site emergency plan • supply information to local authorities for off-site emergency planning purposes • provide certain information to the public
COSHH & EH40/2005 WELs	*Control of Substances Hazardous to Health Regulations 2002 (COSHH) & EH40/2005 Workplace Exposure Limits – Approved Code of Practice (L5)*, Sixth Edition, 2013; See also *Working With Substances Hazardous to Health: A Brief Guide to COSHH (INDG136)*, Revision 5, 2012.	The employer must control workplace diseases resulting from exposure to hazardous substances by carrying out adequate assessments of risks to health arising from work activities involving such substances. WELs, as set out in EH40/2005) are defined which must be adhered to. The assessments must include the introduction of adequate control measures, maintenance of these controls and associated equipment, and monitoring the effectiveness of the measures and health of employees.

Primary Health and Safety Legislation (and Guidance if Available) as of late 2015		Legislation Summary
Reference	**Title**	
CDG 2009, ADR 2015 & RID 2015	*Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009 ('CDG 2009') & European Agreement Concerning the International Carriage of Dangerous Goods by Road 2015* (ADR 2015), *Regulations concerning the International Carriage of Goods by Rail* (*Règlement Concernant le Transport International Ferroviaire des Marchandises Dangereuses)* (RID 2015).	These regulations deal with the carriage of dangerous goods, with the aim of protecting everyone – those directly involved (such as consignors or carriers) and those who might become involved (such as members of the emergency services and public). These regulations place duties upon everyone involved in the carriage of dangerous goods to ensure that they know what they have to do to minimise the risk of incidents and guarantee an effective response. Dangerous goods are substances and articles containing them, classified to be potentially dangerous (hazardous) when carried. Dangerous goods are assigned to different classes depending on their predominant hazard in accordance with international criteria (see ADR 2015).
ROGS 2014	*Railways and Other Guided Transport Systems (Safety) Regulations 2006 (as amended) (ROGS) 2014 – A Guide to ROGS*, ORR, Fourth Edition, October 2014; Office of Rail Regulation, Common Safety Method for Risk Evaluation and Assessment, Guidance on the Application of Commission Regulation (EU) 402/2013, Issue 1, 2015.	These regulations introduce a common framework for safety across all railways or guided transport. They apply to all duty holders (transport undertaking, infrastructure manager, transport operator, entity in charge of maintenance (ECM)) and place requirements that adequate safety management systems are maintained; appropriate safety verification is undertaken of the activities (including independent verification); safety certificates and authorisations are obtained from the competent authority for those activities based on suitable risk assessments and risk controls for these activities with specific requirements for annual safety reports, cooperation, safety critical work and on ECMs.

Primary Health and Safety Legislation (and Guidance if Available) as of late 2015		Legislation Summary
Reference	**Title**	
Waste (E &W) Regs. 2014	*Waste (England and Wales) (Amendment) Regulations 2014*	These regulations place duty of care requirements that: waste is stored correctly (that is to say it must be properly contained); it is only collected by registered waste carriers (unless being moved by the waste producer's own vehicles); all collections are covered by a valid transfer note that includes a written description of the waste to enable anyone handling it to do so safely and appropriately; records of transfers of waste are kept for at least two years; waste must only be taken to an authorised facility that has the necessary waste management, licensing noting that ignorance of the disposal site is no defence if your waste is found fly tipped.
EPR 2010	*Environmental Permitting (England and Wales) Regulations (EPR) 2010 – Core Guidance, 2013*	These regulations address the permitting by the competent authority of activities which could impact on the environment and human health, stipulating the requirements to minimise damage to the environment and human health, permits to cover water and air pollution, radioactive contamination and other environmental hazards.

Appendix B – Current Relevant Good Practice

This appendix presents a summary of the key legislation identified which, whilst not being directly applicable to the GDF, can be defined as being relevant good practice to be taken into account in the GDF project. This is presented in the following table.

Table B1 Legislation summary – relevant good practice

Health and Safety Legislation (and Guidance if Available) as Relevant Good Practice as of late 2015		Legislation Summary
Reference	**Title**	
Mines 2014	*Mines Regulations 2014* *Guidance on Regulations (L149)*, First Edition, 2015; *First Aid at Mines, Approved Codes of Practice (L43)*,First Edition, 1982; See also *Electrical Safety in Mines (HSG278)*, First Edition, 2015	The aim of these regulations is to provide a comprehensive and simpler goal-setting legal framework to ensure that mine operators provide all the necessary protection for mineworkers and others from the hazards inherent to mining. Where general health and safety law adequately covers particular issues, duties are not duplicated in these regulations. This replaces all previous health and safety mining law. It covers general health and safety management of mines; specific measures for the control of major hazards (such as fire protection, explosive atmospheres (including electrical issues), explosives, ground movement, inrushes, shafts, outlets and windings, transport systems); ventilation; mine environment (for example, dust, safety-lamps and lighting); safe exit, escape and rescue; surveyors and plans; tips and tipping.

Appendix C – Conventional Generic Fault Sequence Groups

The GDF operations, as expressed through the process flow description nodes in Table C1 are as follows:

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

Table C1 Conventional Generic Fault Sequence Groups (CgFSG)

CgFSG ID	CgFSG Name	Issue	Hazard Source	Effect	Construction			GDF Operations (Process Flow Description (PFD) Nodes)					
					Surface	Surface to Sub-Surface	Subsurface	N1	N2	N3	N4	N5	N6
C01	Workplace transport hazard	Conventional Injury	Vehicles and Heavy Plant	Vehicle on person low speed impact (crushing between)	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Dropped Loads	Vehicles and Heavy Plant	Route defects resulting in derailment/crash of conveyance during RAM	X	X	X	✓	✓	✓	✓	✓	✓

CgFSG ID	CgFSG Name	Issue	Hazard Source	Effect	Construction			GDF Operations (Process Flow Description (PFD) Nodes)					
					Surface	Surface to Sub-Surface	Subsurface	N1	N2	N3	N4	N5	N6
		Traffic Accidents	Vehicles and Heavy Plant	Vehicle on facility impact	✓	✓	✓	✓	✓	✓	✓	✓	✓
				Vehicle on person impact	✓	✓	✓	✓	✓	✓	✓	✓	✓
				Vehicle on vehicle impact	✓	✓	✓	✓	✓	✓	✓	✓	✓
C02	Working and load at height hazard	Conventional Injury	Lifting Operations	Moving loads and plant movement in vicinity of operators	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Working at Height	General Construction	Construction activities at height	✓	✓	✓	✓	✓	✓	✓	✓	✓
C03	Structural collapse	Conventional Injury	Lifting Operations	Moving loads and plant movement in vicinity of buildings	✓	✓	X	✓	✓	✓	✓	X	X
		Structural Collapse	Excavation	Damage to existing or planned civil support structures	✓	✓	✓	✓	✓	✓	✓	✓	✓
				Unstable or unsupported excavation	X	✓	✓	X	X	X	✓	✓	✓

CgFSG ID	CgFSG Name	Issue	Hazard Source	Effect	Construction			GDF Operations (Process Flow Description (PFD) Nodes)					
					Surface	Surface to Sub-Surface	Subsurface	N1	N2	N3	N4	N5	N6
C04	Plant/machinery hazard	Conventional Injury	Plant and Machinery	Work in areas with moving parts	✓	✓	✓	✓	✓	✓	✓	✓	✓
C05	Fire and explosion hazard	Fire	Infrastructure	Overload or system fault resulting in fire	✓	✓	✓	✓	✓	✓	✓	✓	✓
			Material Storage	Ignition by static or electrical discharge of flammable materials (VOC)	✓	✓	✓	✓	✓	✓	✓	✓	✓
			Vehicles and Heavy Plant	Vehicle battery failure and fire	✓	✓	✓	✓	✓	✓	✓	✓	✓
				Vehicle fuel fire	✓	✓	✓	✓	✓	✓	✓	✓	✓
			Work Equipment	Overload or system fault resulting in fire	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Flammable atmosphere	Excavation	Outgassing of methane from overbearing rock	X	✓	✓	X	X	X	✓	✓	✓
			Material Storage	Ignition by heat source of flammable materials (VOC)	✓	✓	✓	✓	✓	✓	✓	✓	✓

CgFSG ID	CgFSG Name	Issue	Hazard Source	Effect	Construction			GDF Operations (Process Flow Description (PFD) Nodes)					
					Surface	Surface to Sub-Surface	Subsurface	N1	N2	N3	N4	N5	N6
C06	Projectiles and blast, over-pressure hazard	Fire/projectiles	Infrastructure	Overload or system fault resulting in fire or explosion	✓	✓	✓	✓	✓	✓	✓	✓	✓
			Tunnelling	Static discharge resulting in unplanned detonation	X	✓	✓	X	X	X	✓	✓	✓
C07	Airborne hazardous substances and air quality	Hazardous Atmosphere	Excavation	Dust generation from cutting and blasting	X	✓	✓	X	X	X	✓	✓	✓
				Working in confined space	✓	✓	✓	X	X	X	✓	✓	✓
			Materials Handling	Airborne hazardous materials (VOC)	✓	✓	✓	✓	✓	✓	✓	✓	✓
				Generation of hazardous dusts during handling	✓	✓	✓	✓	✓	✓	✓	✓	✓
			Vehicles and Heavy Plant	Dust generation	✓	✓	✓	✓	✓	✓	✓	✓	✓
				Generation of carbon monoxide in exhausts	✓	✓	✓	X	✓	✓	✓	✓	✓
				Generation of noxious	✓	✓	✓	X	✓	✓	✓	✓	✓

CgFSG ID	CgFSG Name	Issue	Hazard Source	Effect	Construction			GDF Operations (Process Flow Description (PFD) Nodes)					
					Surface	Surface to Sub-Surface	Subsurface	N1	N2	N3	N4	N5	N6
				exhaust fumes									
				Reduction in oxygen level (depletion)	✓	✓	✓	X	✓	✓	✓	✓	✓
				Release of ammonia (scrubber) in exhaust fumes	✓	✓	✓	X	✓	✓	✓	✓	✓
C08	Flooding hazard	Structural Collapse	Excavation	Gross water ingress to excavated area	X	✓	✓	X	X	X	✓	✓	✓
		Flood	General Construction	Gross failure during construction activity in a restricted space	✓	✓	✓	X	✓	✓	✓	✓	✓
C09	Electrical hazard	Electrocution/burns	Excavation	Striking in ground electrical distribution services	X	✓	✓	X	X	X	✓	✓	✓
			Infrastructure	Interaction with electrically charged systems	✓	✓	✓	✓	✓	✓	✓	✓	✓
				Striking in ground electrical distribution services	✓	✓	✓	✓	✓	✓	✓	✓	✓

CgFSG ID	CgFSG Name	Issue	Hazard Source	Effect	Construction			GDF Operations (Process Flow Description (PFD) Nodes)					
					Surface	Surface to Sub-Surface	Subsurface	N1	N2	N3	N4	N5	N6
			Work Equipment	Unintended operator interaction with electrically charged work equipment	✓	✓	✓	✓	✓	✓	✓	✓	✓
C10	Noise and vibration hazard	Conventional Injury	Vehicles and Heavy Plant	Noise	✓	✓	✓	✓	✓	✓	✓	✓	✓
C11	Conflict hazard	Conventional Injury	Concurrent operations	Work in conflict with other operations	✓	✓	✓	✓	✓	✓	✓	✓	✓
C12	Occupational hazards	Conventional Injury	Occupational hazards	Work in presence of occupational hazards	✓	✓	✓	✓	✓	✓	✓	✓	✓

For each CgFSG entry, the current key legislation aimed at providing protection against the hazards has been identified. Additionally the practical steps that are being, or will be, considered in the GDF design have been identified. These are summarised in Table C2 with the abbreviations and discussion of the relevant legislation presented in Appendix A of this report.

Table C2 Conventional Generic Fault Sequence Groups (CgFSG) Key Legislation Review

CgFSG No.	Hazard Group	MHSWR 1999	WHSWR 1992	CDM 2015	FSO 2005	LOLER 1998	PUWER 1998	MHOR 1992	WAHR 2005	Vibration Regs 2005	Noise Regs 2005	Confined Space Reg 1997	PPER 2002 & PPEWR 1992 amd	DSEAR 2002 & ATEX 2014	ER 2014	PED & PER 1999	PSSR 2000	EAWR 1989 & BS7671: 2008	ESGCR 2002	COMAH 2015	COSHH & EH40/2005 WELs	CDG 2009 & ADR 2015	ROGS 2014	Waste (E &W) Regs. 2014	EPR 2010
C1	Workplace Transport	✓	✓	✓		✓	✓														✓	✓	✓		
C2	Working and Load at Height	✓	✓	✓		✓	✓		✓																
C3	Structural Collapse	✓	✓	✓																					
C4	Plant/ Machinery		✓	✓		✓	✓																		
C5	Fire and Explosion			✓	✓																✓	✓	✓		
C6	Projectiles and Blast, Over-Pressure			✓			✓					✓		✓	✓	✓	✓	✓	✓	✓	✓	✓			
C7	Hazardous Substances	✓		✓								✓	✓	✓						✓	✓		✓	✓	✓
C8	Flooding	✓		✓								✓												✓	✓

CgFSG No.	Hazard Group	MHSWR 1999	WHSWR 1992	CDM 2015	FSO 2005	LOLER 1998	PUWER 1998	MHOR 1992	WAHR 2005	Vibration Regs 2005	Noise Regs 2005	Confined Space Reg 1997	PPER 2002 & PPEWR 1992 amd	DSEAR 2002 & ATEX 2014	ER 2014	PED & PER 1999	PSSR 2000	EAWR 1989 & BS7671: 2008	ESGCR 2002	COMAH 2015	COSHH & EH40/2005 WELs	CDG 2009 & ADR 2015	ROGS 2014	Waste (E &W) Regs. 2014	EPR 2010
C9	Electrical	✓		✓			✓							✓				✓	✓						
C10	Noise and Vibration	✓		✓			✓			✓	✓		✓										✓		✓
C11	Conflict Hazard	✓		✓																			✓		
C12	Occupational	✓	✓	✓				✓					✓												

Certificate No LRQ 4008580

Radioactive Waste Management Limited
Building 587
Curie Avenue
Harwell Oxford
Didcot
Oxfordshire OX11 0RH

t +44 (0)1925 802820
f +44 (0)1925 802932
w www.nda.gov.uk/rwm