Office for Nuclear Regulation

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1. INTRODUCTION

1.1 The Office for Nuclear Regulation (ONR) has established its Safety Assessment Principles for Nuclear Facilities (SAPs) [1] which apply to the assessment by ONR specialist inspectors of safety cases for nuclear facilities that may be operated by potential licensees, existing licensees, or other dutyholders. The principles presented in the SAPs are supported by a suite of guides to further assist ONR's inspectors in their technical assessment work in support of making regulatory judgements and decisions. This Technical Assessment Guide (TAG) is one of these guides.

2. PURPOSE AND SCOPE

2.1 This TAG provides guidance to ONR Inspectors when assessing the acceptability of a safety case and other arrangements covering the design, construction, operation and closure of a Geological Disposal Facility (GDF) for the disposal of higher activity radioactive waste (HAW). Inspectors should refer to the 2014 White Paper, Implementing Geological Disposal [2] in addition to ONR's approach to regulation of geological disposal and policy on licensing of a GDF [3] for background information.

2.2 The fundamental purpose of a GDF is to dispose of HAW; that is to emplace packaged waste with no intent to retrieve it. A GDF will be constructed at a depth of between 200m-1000m, in a suitable and stable host geological formation, as described in the White Paper. A GDF is a highly-engineered facility, designed using the multi-barrier principle to contain and isolate HAW from the biosphere, protecting people and the environment. In general terms, the multi-barrier principle can be summarised as follows[1]:

- the waste is placed inside a suitable container, and may be immobilised to create a passively safe wasteform;
- the container is then placed within a vault or cell excavated at depth in a suitable and stable host geological formation;
- the surrounding void is filled with an engineered backfill material (eg bentonite or cement); finally,
- once all disposal operations have ceased, the access tunnels are backfilled and sealed to isolate the waste at depth.[2]

2.3 This TAG provides guidance across a range of disciplines for application of the SAPs to the design, construction, operation and closure of a GDF. Where ONR's other TAGs [4] cover relevant topics, this document limits itself to aspects specific to geological disposal, with a reference to more general guidance. Where ONR's existing guidance is considered to be suitable and sufficient for aspects of safety assessment relevant to a GDF, the reader is directed to the relevant TAG or Technical Inspection Guide (TIG) [5]. The Joint Guidance on the Management of Higher Activity Waste on Nuclear Licensed Sites [6] provides guidance on creation and management of waste packages prior to receipt at the GDF.

2.4 The TAG draws upon United Kingdom (UK) legislation and European Union (EU) directive requirements and identifies sources of relevant good practice such as the Western European Nuclear Regulators' Association (WENRA) and International Atomic Energy Agency (IAEA) safety standards.

[1] The choice of disposal concept will depend upon the waste to be disposed of (heat generating or non-heat generating) and the chosen host geological formation.
[2] The facility will be operated such that construction and operation will continue in parallel. As such, some areas may be backfilled and sealed in advance of final closure, and whilst operations continue in other areas.

2.5 At the time of issuing this document, legislative amendments are being developed so that a GDF will become a prescribed installation and therefore subject to the requirements of the Nuclear Installations Act 1965. This means that once a site is selected for a GDF, the developer will need a nuclear site licence and the necessary permissions to be issued by ONR before any nuclear safety related construction can commence on the site.

3. RELATIONSHIP TO LICENCE AND OTHER RELEVANT LEGISLATION

3.1 A GDF is significantly different to any other type of nuclear facility to have been licensed by ONR previously. However, many of the operations that will be conducted on the site are similar to those that are routine on other licensed sites. As such, the majority of ONR's current guidance will be equally applicable to a GDF as for any other nuclear facility.

3.2 For ONR, the novel aspects of regulation are the extent of underground excavation and construction activities, and the fact that the majority of operations involving handling of nuclear matter will be undertaken underground. These factors need ONR to consider other statutory provisions and relevant good practice that are not relevant to other types of nuclear installation.

3.3 This TAG provides additional guidance to underpin application of ONR's existing expectations to a GDF and builds on these by setting out additional multi-disciplinary guidance applicable to a GDF.

3.4 As a licensed nuclear site, a GDF will be subject to the standard Licence Conditions (LCs) [7]. However, the following LCs merit additional consideration with respect to the licensee's undertakings at a GDF:

- LC6 Documents, records, authorities and certificates
- LC11 Emergency arrangements
- LC16 Site plans, designs and specifications
- LC25 Operational records

3.5 In consideration of ONR's purposes, including conventional (non-nuclear) health and safety, other legislation with particular relevance to a GDF is listed below. This list is not intended to be exclusive or exhaustive and other legislation may be relevant for specific activities to be undertaken at a future GDF, depending upon the site location, design, and construction methods:

- Health and Safety at Work etc. Act 1974 (HSWA), and relevant statutory provisions (RSPs) to HSWA
- Construction (Design and Management) Regulations 2015
- Fire Safety (Regulatory Reform) Order (England and Wales) 2005
- Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) 2002
- Ionising Radiations Regulations 2017
- Explosives Regulations 2014

3.6 Standards and good practice applicable to related industries, such as underground construction, may be considered as relevant good practice (RGP) at a GDF. However, it is important to note that standards and guidance developed for other industries may not entirely address the hazards associated with the nuclear aspects of constructing or operating underground. Examples may include, but are not limited to:

- BS 6164:2011 - Code of practice for health and safety in tunnelling in the construction industry [8][3] and the other BS references therein.
- BS EN 60079-14:2008 - Explosive atmospheres. Electrical installations design, selection and erection [8].
- Institute of Civil Engineers Handbook of Tunnel Fire Safety [9]
- Mines Regulations 2014[4]
- US Occupational Safety and Health Administration (OSHA) Underground Construction Regulations (29 CFR 1926.800).

3.7 In addition to the above, a large body of RGP is available from various bodies and institutions (eg the British tunnelling Society (BTS); the International Tunnelling Association (ITA)) along with other operating mines and tunnelling projects worldwide, as well experience from international geological disposal programmes.

Role of the environment agencies

3.8 The environment agencies for England, Wales and Northern Ireland[5] have responsibility for the regulation of disposal of radioactive waste from nuclear licensed sites and other premises using radioactive substances, under the relevant legislation:

- Environmental Permitting (England and Wales) Regulations 2016
- Radioactive Substances Act 1993

3.9 The inspector should be aware of the environment agencies' requirements as detailed in the Guidance on Requirements for Authorisation (GRA) for a GDF on land [10].These include an Environment Case that demonstrates operational and post-closure environmental safety. The Operational Environment Case and the Operational Safety Case for a facility will need to be consistent. The GRA also addresses early activities at potential disposal sites including site investigations.

4. RELATIONSHIP TO SAPS, WENRA REFERENCE LEVELS AND IAEA SAFETY STANDARDS

4.1 The SAPs provide nuclear inspectors with a framework for making consistent regulatory judgements on the safety of activities on nuclear installations, and also recognises the legal duty on licensees to reduce risk so far as is reasonably practicable (SFAIRP).

4.2 There is a range of prescribed activities for which a nuclear site licence is required. Not all of the SAPs are applicable to all facilities; and not all of the applicable SAPs will be relevant to all assessments for that facility. ONR's existing guidance is considered suitable for application to a GDF. However, the objective of this TAG is to provide specific context to the application of the ONR's existing guidance to a GDF.

4.3 In addition to the SAPs, the International Atomic Energy Agency (IAEA) Safety Standards [11] and the Safety Reference Levels (SRLs) developed by the Western European Nuclear Regulators Association (WENRA) [12] are considered to be UK relevant good practice.

4.4 IAEA Safety Standards are developed by international consensus and were used to benchmark the SAPs. The UK, as a member of WENRA, has accepted the Reference

[3] This is currently under revision and the forthcoming changes are expected to be substantial.
[4] Although a future GDF does not meet the definition of a mine, the hazards and management of the risks are aligned to established approaches in the mining industry.
[5] The Environment Agency, Natural Resources Wales, and the Northern Ireland Environment Agency, respectively. The Scottish government does not support geological disposal, favouring a policy of near surface, near site disposal.

Levels and, in line with ONR's enforcement policy statement [13] in relation to relevant good practice, we expect them to be taken into account by licensees.

4.5 The WENRA disposal SRLs [12] have been explicitly considered during development of this TAG. Regulatory responsibility for disposal of radioactive waste rests with the relevant environment agency; hence the majority of the disposal SRLs relate to the vires of the environment agencies. ONR is responsible for regulating the safe and secure construction, operation and closure of the facility. Direct reference is made to each of the SRLs considered relevant to the guidance provided within this TAG. Other disposal SRLs relevant to the vires of ONR and not referenced herein are considered to be adequately captured by other ONR guidance.

5. ADVICE TO INSPECTORS

5.1 A GDF has an anticipated operational lifespan in excess of other nuclear facilities of well over a century. Given the anticipated operational lifetime, provisions should be made by the licensee for maintaining current knowledge and capability on developing RGP, and implementing new technologies, subject to ALARP considerations.

5.2 Further to this, the licensee should demonstrate a commitment to seeking and learning from relevant operational experience, as expected by SAP MS.4. Areas where utilisation of operational experience and learning from experience are particularly pertinent for a GDF are discussed herein.

5.3 ONR would expect there to be appropriate focus on the elimination of hazards through effective application of defence in depth, especially considering the anticipated lifetime of the facility and the potential difficulty in accessing the underground workings following a fault. Furthermore, ONR would expect to see implementation of passive protective measures in preference to active systems in line with the hazard reduction hierarchy.

Management of potentially conflicting requirements

5.4 The licensee will be required to identify and manage different requirements that may impact upon its undertakings which may stem from multiple regulatory regimes, and that may be enforced by different authorities. Examples include, but are not limited to, requirements related to safety (both nuclear and conventional), environmental protection, land use planning.

5.5 This requirement is reflected in WENRA SRL DI-41:

The licensee shall have a process for identifying any conflicting design requirements from different regulatory regimes, and seeking to resolve them.

5.6 An example is safely operating a GDF designed to isolate the waste from the biosphere to prevent harm to present and future generations, and protect the environment. In order to achieve the long-term objective; the design of the multiple engineered barriers will be optimised to deliver post-closure performance. However, the focus cannot solely be on the post-closure performance of the GDF; the workers and the public need to be protected during construction, operation and closure of the facility.

5.7 Development of the operational and post-closure safety cases is an iterative process; the two need to be adequately linked, enabling design requirements or specifications deriving from one regime which challenge the other to be captured, assessed and resolved. Any decisions which may have a detriment to one safety case in order to realise a benefit to the other should be appropriately justified and recorded.

5.8 Monitoring during the operational phase should assist in confirming that safety functions claimed in the post-closure safety case are not undermined by decisions or incidents during the operational phase.

5.9 An additional, but equally important, consideration is the effect of GDF requirements on the safety of operations at the consigning or donor plants. Similarly, GDF and plant safety cases need to be adequately linked to ensure that risks to operators and the public across all phases of the waste lifecycle are as low as reasonably practicable. Limits set to ensure criticality safety and radiological protection may be particularly important in this.

5.10 Further to the requirement for identifying and resolving conflicting requirements from different regulatory regimes, any measures necessary for the purposes of safeguarding nuclear materials should not have an unacceptably detrimental impact to either the operational or post closure safety cases. This requirement is reflected in WENRA SRL DI-31:

The licensee shall ensure that any measures necessary for the purpose of accounting for and control of nuclear material shall not unacceptably affect operational and post-closure safety.

Management of concurrent underground activities

5.11 The licensee's arrangements and safety case for conducting its operations should provide adequate demonstration that safety and security is maintained for all activities the licensee undertakes on the site, at any time. It is expected that a GDF will be operated such that there will be concurrent nuclear and non-nuclear activities underground. That is to say emplacement of waste packages into the facility will commence whilst construction activities continue in other parts of the facility. The licensee will be required to demonstrate that there will not be an unacceptably adverse impact on nuclear operations or Safeguards provisions from construction, and vice versa. This requirement is reflected in WENRA SRL DI-30:

If construction, operation, decommissioning or closure activities take place concurrently, the licensee shall perform the works so that they will not have an unacceptable effect on operational or post-closure safety.

5.12 Separation of construction and nuclear activities may be achieved through creation and maintenance of physical barriers to demarcate separate areas. This may be especially important if separate ventilation system requirements are defined for the nuclear and non-nuclear (construction) areas. Any such barriers should take due consideration of conventional health and safety risk management arrangements.

5.13 Access and egress routes for materials and persons should be considered so as to maintain appropriate separation. Controls may be required to ensure persons only have access to the appropriate area(s).

5.14 Adequate testing arrangements should be in place to ensure that the hand-over from construction to operations does not adversely impact the safety or security of the facility. Robust arrangements should be put in place in terms of control and instrumentation to ensure compatibility through the construction and operation periods.

5.15 The impact from excavation techniques employed during construction should be considered. For example, in hard rock scenarios drill and blast excavation techniques may be utilised, introducing an explosion hazard. Such activities should be appropriately controlled to minimise any adverse impact on separate activities ongoing elsewhere in the facility. Additionally, controls on the use and storage of explosives should demonstrate how nuclear safety is maintained. See also paragraphs 5.54 to 5.57 and NS-TAST-GD-014 [4].

5.16 The backfilling strategy for the facility should be appropriately justified so as to ensure that risks from waste emplaced in the facility are controlled so far as is reasonably practicable. There are benefits and dis-benefits to the timing of installation of the engineered backfill. For example, delayed backfilling may facilitate waste package monitoring to confirm package integrity, but early backfilling may reduce impact from ongoing activities on the emplaced wasted. The licensee's strategy should clearly set out the benefits and dis-benefits to justify the proposed approach and demonstrate ALARP. It should be noted that a different strategies may be appropriate for different categories of waste.

Reversibility and retrievability of radioactive waste

5.17 The terms reversibility and retrievability are used internationally to refer to slightly different concepts [14]; the OECD Nuclear Energy Agency (NEA) has adopted particular definitions [15] illustrating the trade-offs between the ease and cost of waste retrieval, and active versus passive safety. The IAEA define retrievability as the ability to remove from where it has been emplaced [16].

5.18 In practice, 'retrievability' is used as an umbrella term for removing a waste package from the GDF. However there are nuances depending upon at what stage the operation were to take place; in the UK, the following terms have been adopted by the Committee on Radioactive Waste Management (CoRWM) [17]:

- Reversibility – denotes removal of a waste package by reversing the original emplacement process, implying the backfill has not been installed. This can also be used to mean reversal of decisions made in the progressive implementation of a disposal concept.
- Retrievability – denotes removal of a waste package after the backfill has been emplaced, utilising a different process to the original emplacement process, during the operational phase.
- Recoverability – denotes the process of recovery of waste after closure of the GDF, utilising mining or other similar intrusive methods.

5.19 All three definitions refer to the removal of waste from the GDF; the difference being the perceived degree of difficulty involved due to elapsed time and installation of any engineered barriers after emplacement.

5.20 Retrievability of waste from a GDF is discussed in the 2014 White Paper [2], which states that during the operational stage, emplaced waste could be retrieved if there was a compelling reason to do so. As regulator, ONR's role is to ensure that the licensee discharges its legal duties related to any decision regarding retrieval of waste.

5.21 Although the intent of disposal is not to retrieve waste, this is not incompatible with the concept of retrievability; design, construction and operation of a GDF could be conducted so that the option to retrieve waste in the future is not precluded. However, any provision in the design, construction or operation of a GDF facilitating retrievability should not adversely affect safety and security. The licensee should take due account of requirements from other regulatory regimes when considering any provision to facilitate retrievability.

5.22 A decision to retrieve one or more emplaced waste packages should be considered by the Inspector in the context of the safety case and the arrangements in place for such an operation. ONR expects the licensee to adequately justify the intended operation and demonstrate that the safety consequences of retrieval are ALARP [4].

5.23 A waste package that is emplaced in its final location within the GDF is considered to be disposed of. Consequently, this is not considered to be an accumulation of radioactive waste, even if provisions that would facilitate its retrieval are included in the design of the facility. However, the licensee should still have appropriate arrangements under LC 32 (Accumulation of radioactive waste) for minimising, so far as is reasonably practicable, the rate of production and total quantity of radioactive waste that may arise from its handling of nuclear matter on the site.

5.24 Furthermore, any decision to retrieve or recover waste packages, at any time in the facility's lifecycle, could be a significant factor in the eventual safeguards approach. Any provision to facilitate reversibility or retrievability may impact upon the type of safeguards provisions installed for containment/surveillance of the GDF (eg cameras, radiation monitors, safeguards seals or seismic equipment) and remote data transmission from these to the safeguards authorities.

Timing of backfilling

5.25 Multi-barrier disposal concepts consist of the waste package (consisting of the wasteform and container), the backfill material, and the natural barrier provided by the host geological formation. After emplacement of the waste packages has been completed, the void around the packages is then filled with an engineered backfill material to provide additional containment and protection of the waste packages, and also to provide support to the surrounding rock formation.

5.26 However, it may not be necessary for all voids to be backfilled with some access tunnels intended to remain open into the post closure period. The time at which backfilling is completed may be dependent upon a number of considerations with potentially competing benefits and dis-benefits to operational safety and post-closure performance (see paragraphs 5.4 to 5.10). For example, prompt backfilling of the void around waste packages places the waste into the most stable configuration for long-term performance at the earliest opportunity, and mitigates the risk of a rock fall impacting the waste packages. However, delaying backfill provides the opportunity for direct monitoring of waste packages; facilitates the potential for retrieval of waste packages (if required, see paragraphs 5.17 to 5.23); and affords the opportunity to research the behaviour of the local host geological formation to underpin assumptions in the post-closure safety case. Decisions made regarding the timing and extent of backfilling will be required to be adequately underpinned to demonstrate ALARP, and that the relevant environment agency's requirements have been met.

5.27 Backfilling decisions will be influenced by the type of waste (eg heat generation characteristics) and the host geological formation for the facility (eg structural strength of voids); other factors may also need to be considered depending upon the design of the facility.

Retention of Records Important to Safety

5.28 A record provides objective evidence of an activity performed or results achieved and can be a document or a physical item. Records are of strategic importance to a licensee and are an asset that needs to be properly managed. The licensee will have duties under the licence to make adequate records to demonstrate compliance with any of the LCs attached to the licence. Furthermore, particular operational records are required [7]. Records should enable a licensee to demonstrate how it has acted and how it has complied with the requirements of the licence condition and other regulatory requirements.

5.29 Electronic record management systems and electronic data have become standard across industry. The licensee's continued ability to read the data must be assured and considered taking into account the technological changes that may occur between making the record and its subsequent retrieval. Given the extended operational lifetime of a GDF, the licensee should make provision for periodically upgrading the record or record management in line with new technology, taking into consideration:

- fidelity of data over time and disaster recovery arrangements (information backup); and
- compatibility of storage mediums and software changes which have the potential to impact future data access.

5.30 General ONR guidance on retention of records is provided in NS-TAST-GD-033 [4], which supports numerous SAPs relating to records (eg EMC.20, RW.7, DC.6), and with additional guidance in NS-INSP- GD-006 and NS-INSP-GD-025 [5]. Guidance on records relating to radioactive waste is provided in the Joint Guidance [6].

5.31 Notwithstanding the available ONR guidance, retention of records will be especially important for the GDF given the extended operational lifetime compared to other nuclear facilities.

5.32 The record retention schedule should be considered from the initial site investigation / desk study stages. The various datasets and site models (such as geological, geotechnical, hydrogeological etc) should be maintained throughout the life of the GDF to support demonstration that the as built status of the facility has been maintained and meets the design requirements for the post closure safety case; the importance of such data should not be underestimated, for example, to analyse fault sequence progressions and inform where flexibilities or alternative design options should be pursued as the concurrent phases progress, in addition to longer term periodic safety reviews (PSRs).

5.33 Retention of records of disposed waste packages will be crucial to demonstrating safety for ongoing operations. Packages disposed of to the facility will continue to present a hazard to those working on the site after their emplacement, especially given construction and waste emplacement will be undertaken concurrently. Consequently, the licensee should be able to demonstrate knowledge and the location of the waste that has been disposed of to the facility.

5.34 In addition to records related to the licensee's undertaking, the arrangements should address retention and retrievability of the necessary waste package records, covering the full lifecycle of the waste from generation, through processing, storage, transport and final disposal.

Asset management

5.35 Asset management is identified as a key strategic factor to the safe and secure management of the UK's new and existing nuclear infrastructure. ONR considers Asset Management to be important for dutyholders in order to effectively manage all facilities on a nuclear licensed site that have the ability to result in safety significant consequences. Our expectation is that licensees shall conform to the relevant good practice as described in ONR guidance, subject to ALARP, including in particular:

- NS-TAST-GD-098 – Asset Management
- NS-TAST-GD-009 – Examination, Inspection, Maintenance and Testing of Items Important to Safety
- NS-TAST-GD-050 – Periodic Safety Reviews
- NS-INSP-GD-015 – LC15 Periodic Review
- NS-INSP-GD-028 – LC 28 Examination, Inspection, Maintenance and Testing

- SAPs EAD.1-EAD.5 and EMT.1-EMT.8

5.36 The licensee should consider the provision of appropriate examination, inspection, maintenance and testing (EIMT) in the context of sustainable development during widely changing operating regimes and changing operating requirements. The infrastructure within the facility must be capable of reliable service throughout its design lifetime and enabling delivery of the necessary function from one generation to the next. Furthermore, capability and capacity for facility refurbishment or extension should be considered, both for surface and sub-surface facilities.

5.37 Waste packages that have, or are likely to attain a pressure of 0.5 bar greater than atmospheric pressure will be subject to the Pressure Systems Safety Regulations (PSSR) 2000. PSSR places a clear duty on the duty holder to ensure that the equipment is examined properly and in accordance with a written scheme of examination. PSSR allows a duty holder to exclude parts of the system from the scope of the written scheme provided they are able to justify their decision. In addition, during the transport of waste packages the Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009 (CDG) apply. For further guidance on pressure systems safety, see NS-TAST-GD-067 [4].

5.38 Application of PSSR to waste packages emplaced in a GDF may necessitate the licensee conducting examination or inspection of the waste packages. Where packages have been backfilled and such examination is not possible, indirect measurement of the integrity of the system would be expected, for example through environmental monitoring to confirm there has been no release of radioactive material.

Package handling operations

5.39 ONR’s expectation is that movement of waste packages from the above ground receipt and storage area to the underground facility will be carried out using approved transport packages. If packages are to be unloaded from a transport package above ground to facilitate transfer to the underground disposal location, there should be a robust demonstration that the proposed operations are ALARP.

5.40 ONR’s guidance on nuclear lifting operations is provided in NS-TAST-GD-056 [4]. This guidance, although generally applicable does not consider the specific requirements applicable to underground activities. The licensee’s arrangements and safety case should provide adequate demonstration that the all operations, from installation to maintenance, consider the added difficulties of working in underground tunnels, shafts, chambers and passageways. These can include reduced light conditions, difficult or limited access and egress, with the potential for exposure to air contaminants and the hazards of fire and explosion.

5.41 Other standards that may be applicable are derived from the Supply of Machinery (Safety) Regulations 2008, the Lifting Operations and Lifting Equipment Regulations 1998 (LOLER) and the Essential Health and Safety Requirements of the Machinery Directive. However any requirements of these design standards may not necessarily adequately address all the hazards associated with a nuclear lift, particularly if the lift is below ground.

Underground construction techniques

5.42 BS 6164:2011 makes recommendations for and gives guidance on practices in shaft sinking, tunnel construction, tunnel maintenance, renovation and repair. The 2011 revision of BS 6164:2011 takes into account the advances in technology and equipment that are available to the tunnelling industry. It also takes account of new techniques and the effect of changes in legislation and guidance relating to health and safety, and environmental matters. BS 6164:2011 is written for all involved in tunnelling projects and addresses the safety of both those engaged in the tunnelling process and those who could be affected by it. The standard includes recommendations that are also relevant to cut-and-cover tunnelling, immersed tube tunnels and other forms of underground construction as well as to the maintenance, renovation and repair of shafts and tunnels. The recommendations are not intended to apply to the construction of shafts or tunnels for the purpose of mineral extraction.

5.43 The inspector should note the importance of the design, collection and interpretation of the site specific ground investigation for the construction of the GDF, as this information forms the basis for the selection of appropriate construction techniques and the design of the facility. Further guidance on design safety assurance can be found in NS-TAST-GD-057 [4].

5.44 The inspector should ensure that the principles of the SAPs, particularly those of AV.1, AV.3, AV.4, AV.7, AV.8, & ECE.5, regarding data collection, uncertainty, validation, building of models, and independent peer review have been met. Such data are also applicable to the derivation of some external hazards as highlighted in SAP EHA.2; this is discussed in more detail in NS-TAST-GD-013 [4].

5.45 The main code of practice for the UK is BS 6164:2011 Code of practice for health and safety in tunnelling in the construction industry [8], although it should be noted that this is currently under revision and changes are expected to be substantial. Much of the health and safety guidance is produced by the British Tunnelling Society (BTS) and the International Tunnelling Association (ITA) – specifically under Working Group 5[6]. Inspectors should also be aware that guidance has been produced by Crossrail (this can be found on the BTS website[7]) which may be a useful source of RGP.

5.46 Other useful guidance can be found from within the mining industry and the various research and development programmes applicable to this area e.g. tunnelling technology and similar such projects worldwide.

5.47 Due to the specialist nature of such works the inspector is advised to seek specialist advice from both Her Majesty's Inspectorate of Mines (HMIM) and HSE Construction Division in support of their assessment of dutyholder submissions.

Geotechnical validation of underground tunnels and vaults

5.48 ONR's existing guidance on construction assurance is provided in NS-TAST-GD-076 [4]. BS 6164:2011 [8] provides guidance in relation to the geological and geotechnical testing that should be undertaken (§5.3 Project Specific Studies) to validate constructed tunnels and vaults. Guidance on the Mines Regulations 2014 is provided by HSE [18], which covers control of ground movement and is considered to be RGP for a GDF.

5.49 The sampling and testing scheme should be tailored specifically to the requirements of the investigation. Logging and testing should be undertaken in accordance with BS 5930 [8] and Eurocode 7 [8]. Additional guidance is available in the *UK Specification for Ground Investigation* [19] published by the ICE.

5.50 Geotechnical logging should be used to inform the design and construction of excavations in rock (including the support system); a number of systems have been developed to reliably characterise rock masses and provide input data to the design analysis. Use of an industry standard system would be expected or otherwise justified by the licensee. Validation of the models and outputs should be undertaken, in accordance with SAPs AV.1 to AV.8.

[6] https://www.ita-aites.org/
[7] https://www.britishtunnelling.org.uk/

5.51 Geotechnical information should be acquired by advance drilling ahead of excavation work and the geological model updated accordingly. This can give warning of hazards or changes in ground conditions, improving the overall quality of the data and associated tunnel construction. The Licensee's arrangements should clearly identify the process for determining whether ground conditions are adequate for development. Logging should be undertaken following excavation to confirm or update the geological model. Where the ground is found to be unsuitable (eg fracture / shear zones), ground improvement may be possible allow development in that area, or the design may be revised to avoid construction in the affected area. Any design changes should be subject to the licensee's management of change process. Geotechnical investigations for assurance of underground constructions should consider, and adequately mitigate, potential impacts on the post-closure safety case. As-built records should be maintained, in accordance with the requirements of Eurocode 7 and LC 25.

5.52 It may be considered appropriate to use geophysical techniques to supplement the other geotechnical data sources. Geophysical techniques should be applied in accordance with BS 5930, Eurocode 7 and other relevant codes and standards as appropriate.

5.53 Long term monitoring of the GDF from a civil engineering perspective is also critical and the inspector should ensure that the design and installation of such monitoring systems are suitably robust with adequate redundancy to ensure continuity of data over the GDF design life.

Application of Internal Hazards to underground working

5.54 Internal Hazards are defined in NS-TAST-GD-014 [4] as *those hazards to plant, structures and personnel which originate within the site boundary but are external to the process,* that result in a radiological consequence either by directly releasing radioactive material or by affecting the performance of nuclear safety related structures, systems or components (SSCs). This should include consequential hazards (such as a seismic event causing a dropped load which results in a radiological consequence) and the effects of concurrent operations (for example where construction of new disposal vaults is undertaken simultaneously with nearby emplacement of radioactive waste).

5.55 Hazards present within an underground structure will typically be the same as for a surface structure (as discussed in NS-TAST-GD-014 [4]), however there may be different initiators, consequences and protective measures. The licensee should be able to demonstrate that they are aware of, and have responded to, the unique challenges presented by working underground. BS 6164:2011 [8] provides useful guidance which needs to be interpreted in a nuclear context.

5.56 There is a general expectation that the licensee should consider compartmentalising the installation so that any potential impacts of internal hazards may be limited to one area and thus reducing the extent of the consequences, in particular for fire and flood events. Consideration should also be given to provision of multiple access/ egress routes (for both personnel and services) such that a single event does not result in isolation of a significant portion of the installation.

5.57 Some of the key internal hazards and unique aspects relevant to underground working are listed below, noting the list is not exclusive or exhaustive:

- internal flooding – inrush, initiation by seismic events/ explosions and management of firefighting water;
- fire – retention of heat in surrounding rock, monitoring/ suppression systems;

- toxic and flammable gas release – migration through porosity/ microfractures, evolution by radiolytic degradation and sulphur reducing bacteria, use of a reversible ventilation system;
- collapses – impact of different rock types;
- dropped loads – minimisation of drop height during import and emplacement of radioactive material;
- impacts from vehicular transport – including elevators;
- pipe whip/ jet impingement; and
- explosion/ missiles.

Underground conventional safety hazards

5.58 Hazards relevant to conventional health and safety are discussed in BS 6164:2011 [8]. Hazards include those common to surface-based construction (eg trips, slips and falls, pinch-points, moving machinery, fire etc) in addition to those specific to the underground environment. The latter comprise, but are not limited to:

- geotechnical instabilities (eg roof fall, rock bursts);
- inrush (flooding);
- dust (eg non-respirable atmosphere and potential for build-up of an explosive atmosphere); and
- specified risks giving rise to confined spaces.

5.59 Guidance on the Mines Regulations 2014 is provided by HSE [18], which covers control of major underground hazards and is considered to be RGP for a GDF.

Application of External Hazards to underground working

5.60 In addition to the above, other external hazards pertinent to a GDF are in part discussed in the External Hazards TAG [4] and its technical annexes; however the guidance does not highlight some of the hazards specific to a GDF. Examples of such hazards may include, but are not limited to:

- pockets of pressurized gases e.g. methane;
- groundwater;
- fault rupture (capable faulting);
- fault creep; or
- ground motion arising from geological or induced seismicity.

5.61 The dutyholder is expected to have a robust process to identify applicable external hazards as per the intent of SAP EHA.1 and EHA.19.

Underground fire prevention, detection and protection

5.62 A GDF is not required to comply with either the UK Building Regulations Approved Document B (ADB) [20] or BS 9999:2017 Fire Safety in the Design, Management, and Use of Buildings [8], but the general fire safety principles remain valid. The licensee should therefore develop a full fire engineered design that follows the principles of BS 7974 Application of Fire Safety Engineering Principles to the Design of Buildings [8] and the statutory requirements of the Fire Safety Order 2005. The basic principles to be addressed are summarised as:

- adequate means of escape;
- fire detection, alarm & suppression systems;
- robust system of managerial control;
- control of combustible materials;
- fire resistance and suitable compartmentation;
- access & water supplies for emergency services; and

- adequate ventilation arrangements for control and extraction of smoke.

5.63 The licensee should consider the chemical compatibility between any means used to extinguish a fire underground, the waste packages and the host geological formation. Post-fire effluent management should also be considered in the design of the fire protection system(s), taking due consideration for the potential depth of the facility, and that the effluent may be contaminated.

5.64 The host geological formation will influence the provision of fire protection and detection systems, including routing of power cabling and routing of supply pipes for extinguishing media (if installed). Underground fire protection and detection systems should demonstrate signalling integrity of control panels and devices (eg if a Wi-Fi system is installed), and secure communication arrangements between the underground workings and the surface facilitates.

5.65 BS 6164:2011 [8] provides detailed requirements for ensuring health and safety during tunnelling and underground construction activities, including for provision of fire prevention and detection systems. RGP from the UK mining industry should be applied at a GDF, in addition to consideration of RGP internationally [eg 21,22].

5.66 In order that the assessment scope of all fires is correctly considered and proportionate, the concept and definition of a 'nuclear fire'[8] should be made clear in all documentation discussing fire in the GDF. Identification of when a fire is solely conventional and when a fire has the potential to lead to release of nuclear material must be stated clearly.

5.67 The potential for fire initiation and growth and the possible consequences on items important to safety should be determined [SAPs – EHA.1, EHA.14 & EKP.5] to confirm the adequacy of fire resistant boundaries and the capacity and the capability of the fire detection and fire-fighting systems designed to limit the spread of fires [ECS.2, ECS.2 & EHA.16].

Underground nuclear and non-nuclear ventilation systems

5.68 The main function of ventilation systems for nuclear applications is to support the physical containment in controlling and minimising the escape and spread of radioactive contamination. ONR guidance on nuclear ventilation systems is provided in NS-TAST-GD-022 [4] and ISO 17873:2004 – Criteria for the design and operation of ventilation systems for nuclear installations other than nuclear reactors.

5.69 The ventilation system for a GDF will be required to provide this function (eg. in the event of a release of airborne radioactive material) in addition to the more conventional application during underground construction, which is to provide a respirable atmosphere (by removing or diluting pollutants, preventing the build-up of explosive atmospheres) and a comfortable ambient temperature. Guidance on system requirements is available in the Code of practice for health and safety in tunnelling in the construction industry (BS 6164:2011) [8].

5.70 The capacity and flexibility of the ventilation system(s) should be considered at the design stage to ensure that the progressive development of the facility and increase in waste package numbers (and hence in potential for radioactive and explosive gas generation) are adequately planned for. Adequate margins should be built into the design to give sufficient recovery time in the event of a failure of parts or all of the ventilation system(s). This should address potential build-up of both radioactive and explosive gases.

[8] A 'nuclear fire' is one which has the potential to cause the release of nuclear matter into the environment.

5.71 Fresh air must be supplied to all underground work areas in sufficient quantities to prevent any dangerous or harmful accumulation of dust, fumes, mists, vapours or gases. If natural ventilation does not provide the necessary air quality through sufficient air volume and air flow, this must be provided by mechanical ventilation, designed to meet an appropriate standard, eg The Mines Regulations 2014.

5.72 The differing functional requirements should be considered in the design of the ventilation system. The safety case should provide adequate demonstration that the ventilation system adequately manages the ventilation requirements during all phases of operation from construction through operation, under both normal and abnormal (accident) conditions.

Emergency escape provisions and refuge areas

5.73 Arrangements should be in place to ensure that emergency equipment including personal protective equipment are available where required and maintained to the required standard, such as breathing apparatus, spill kits, etc. Such arrangements should also ensure enough safety officers are trained to respond.

5.74 Requirements for provision of self-rescue equipment and underground refuge areas are provided in BS 6164:2011 [8]. For example, requirements are for a minimum of 20 minutes oxygen/walking re-breathers to be supplied to all personnel to enable access to a place of ‘relative safety’. This will likely require the provision of multiple adequate refuge areas, given the anticipated distances required to travel from below ground to ‘ultimate safety’. Any such refuge areas should be sited in low potential radiation dose areas, have clear maximum occupancy and provide the following:

- an adequate level of fire resistance;
- adequate ventilation and supply of fresh air;
- hard wired communications systems allowing direct contact with the surface;
- radiation shielding, if necessary;
- fail-safe emergency lighting;
- independent power supplies; and
- other occupant considerations such as seating, drinking water, and either a heating system or provision of blankets.

5.75 The licensee should ensure that emergency refuge areas are clearly marked on all site plans and that appropriate information and training is provided to all personnel on the site in their location and use. The licensee should also ensure that the site plan is updated as appropriate during construction to adequately reflect the underground layout to assist with emergency planning and training. The number of personnel underground should be managed to ensure the provisions for escape in an emergency are adequate, at all times.

5.76 In order to ensure that learning from experience is applied to emergency escape aspects of the GDF, regular reviews of accidents around the world involving emergency response in underground facilities should be performed.

5.77 ONR would expect the licensee to hold membership to Mining Association UK (MAUK), enabling access to mutual escape and rescue arrangements with other underground operators. Furthermore, guidance is available from the Government Chief Fire & Rescue Advisor as contained in Generic Risk Assessment 2.7, Rescues from tunnels and underground structures [23].

Underground vehicles

5.78 Use of diesel or electrically powered vehicles underground should be justified by the licensee, demonstrating the risks of using diesel fuel or electric batteries are controlled to be ALARP; requirements and guidance on the use of underground vehicles is provided in various British Standards (BS) [8]. In general all such vehicles must have their own local fire extinguishment systems, usually dry powder or CO_2, and provision of adequate ventilation of the areas in which they are to be operated. In considering these risks, cognisance is required of the specified risks that might give rise to the creation of a confined space.

5.79 The licensee should understand the proposed amendments to Directive 2004/37/EC for tighter controls on Diesel Engine Emissions (DEE) and NO_2, NO and CO which may affect the blasting regimes and ventilation controls in use during construction and ongoing development.

5.80 RGP on the use of underground railways and funiculars is available from the mining industry.

Monitoring at a GDF for operational safety and safeguards purposes

5.81 Consideration should be given to developing the operational monitoring strategy and establishing the required infrastructure to support the range of monitoring required for the various phases of the facility at the early stages of design development. In addition to monitoring, alarm systems which respond to the parameters being monitored must also be considered at early design stages. Some of the aspects to be monitored may include, but are not limited to:

- radiation contamination and shine paths to inform alarm, ventilation responses, evacuation, etc.;
- toxic or explosive gases and dusts;
- smoke and heat to inform fire alarm and response systems;
- air pressure (differential pressures between areas) to inform ventilation management systems;
- ventilation damper positions and condition;
- rock movements (creep, cracking, etc.);
- water ingress; and
- status and condition of safety related systems, structures and components.

5.82 Monitoring of external hazards at the site from site selection and throughout the operational life of the GDF is an important aspect that will be critical for demonstrating continued safety of the facility, particularly for periodic reviews as required by LC15. In addition to the considerations in the External Hazards TAG [4], due to the nature of the GDF other specific monitoring may be appropriate, such as surface deformation, heat transfer, groundwater flow, or seismicity[9].

5.83 Long-term operational monitoring of the GDF from a civil engineering perspective is also critical and the inspector should ensure that the design and installation of such monitoring systems are suitably robust with adequate redundancy to ensure continuity of data throughout the anticipated operational period. Inspectors should note that the British Tunnelling Society have published a specific guide on Monitoring Underground Construction [24].

5.84 Arrangements for above and below ground monitoring of ionising radiation (e.g. dose rates, surface contamination, air concentrations) should be in place. The arrangements are required to provide information of radiological conditions on an ongoing basis to ensure exposure to ionising radiation is controlled and restricted as required by IRR17. These include:

[9] The British Geological Survey currently operates a UK wide seismic monitoring network.

- ensuring areas are adequately designated and that working conditions in those areas are kept under review,
- determining radiation levels and contamination from operations so appropriate controls for restricting exposure can be implemented and maintained
- detecting break down in controls or systems and
- individual dose estimation, recording and health surveillance.

5.85 Consideration should be given to warning and or detection systems to deter and detect unauthorised tunnelling towards the licenced site volume.

5.86 Consideration needs to be given to the possible impact of any independent verification of the Nuclear Material Accountancy and Control (NMAC) systems and procedures, safeguards reports and physical/nuclear material inventory verification during design, construction, operation and post-closure phases. The safeguards authorities can verify the NMAC systems/procedures; nuclear material inventories; and the physical structure of the GDF.

Safeguards verification for disposed nuclear materials

5.87 The transport and disposal of any nuclear material subject to safeguards in the GDF will require safeguards verification. This verification is to provide independent assurance that nuclear material is not being diverted from its declared disposal and that the NMAC system is suitably robust.

5.88 The current requirements in the Euratom Regulation 302/2005 [25] includes an explicit reference to the application of safeguards to nuclear materials[10] in 'waste', which is defined in the Regulation as:

…nuclear material in concentrations or chemical forms considered as irrecoverable for practical or economic reasons and which may be disposed of.

5.89 The guidelines to Euratom Regulation 302/2005 incorporate more detail on the proposed safeguards coverage for a wide variety of nuclear materials in wastes, including suggested concentration levels below which Euratom safeguards may be terminated. The IAEA also has interest in the application of safeguards at a GDF, which in the UK will be recognised as a facility under INFCIRC/263 [26] (or its agreed replacement after the UK exits the European Union), the trilateral safeguards agreement between the UK, Euratom and the IAEA.

5.90 GDF NMAC systems, and associated procedures and records must be designed and implemented in a way that gives assurance to Safeguards authorities that civil nuclear materials in waste destined for disposal to a GDF are not diverted for other undeclared purposes.

5.91 Some of the waste destined for a GDF will contain significant quantities of nuclear materials. In consultation with the UK Government and the licensee, the safeguards authorities will agree a suitably proportionate approach to meeting the UK's safeguards requirements based on disposal system design, operational constraints and nuclear materials type, quantity and form. The safeguards approach should therefore be commensurate with the perceived safeguards risk at each stage of the waste lifecycle.

5.92 Important considerations when developing the safeguards strategy include the ability to account for and verify the nuclear material content and the physical structure of the GDF, and to maintain a continuity of knowledge following these verification

[10] Nuclear materials are any form of uranium, plutonium and thorium. The UK also provides the International Atomic Energy Agency (IAEA) with reports on certain quantities of americium and neptunium.

measurements, during operation and following closure irrespective of the point in the process at which this verification is performed. Post-backfilling verification could include such measures as records based accountancy and review of any containment/surveillance measures given the lack of access to emplaced packages.

5.93 The safeguards approach at a GDF will be overseen by ONR Safeguards. Wastes containing safeguards significant quantities of uranium, plutonium or thorium derived from the UK civil nuclear programme are likely to be subject to international safeguards and as such, reported to the Safeguards inspectorate via ONR Safeguards.

5.94 Safeguards reporting requirements shall be met in accord with the safeguards obligations and agreed approach.

5.95 Currently, information on the design and operation of a GDF shall be provided to the European Commission at least 200 days before construction commences and updated periodically. More detailed technical information on the design, operation, nuclear material flow, and nuclear material accountancy and control system is subsequently required 200 days before the first receipt of nuclear materials. Similar requirements are expected under any new safeguards regime, although the exact detail may be slightly different.

Decommissioning considerations

5.96 ONR's expectation for decommissioning at a GDF is aligned to those at any other facility: licensees adequately consider decommissioning during design, to minimise hazards presented during decommissioning, and ensure appropriate application of the waste management hierarchy to minimise generation of decommissioning waste. The licensee should have adequate arrangements for decommissioning of the facility, proportionate to the current stage of the facility lifecycle to the as per NS-TADT-GD-026 [4]. Particular attention should be given to records of the as-built state of the facility, and its evolution over its lifetime, and records of the waste inventory and its emplacement.

5.97 The licensee's decommissioning plans should take due account of the requirements of the post-closure safety case, in accordance with WENRA SRL DI-68 which states that:

The licensee shall close the disposal facility in such a way as to provide for the safety functions required after closure.

for example, decisions to leave in-situ materials or equipment that could adversely affect the safety functions of the GDF after closure should be appropriately justified.

5.98 Decommissioning and closure activities must include consideration of ongoing reporting and physical/nuclear material inventory verification requirements, particularly post-closure. These requirements must be agreed with the relevant safeguards authorities well in advance of the activities commencing. This is in accordance with the specific reference to security and safeguards during decommissioning in WENRA SRL DI-69:

Before starting decommissioning and closure, the licensee shall define the corresponding program so that it takes into account, as appropriate:

- *The state of the facility, as constructed and operated including information on waste inventory and emplacement;*
- *Dismantling and removal of operational equipment;*
- *Remaining backfilling and sealing;*

- *Decommissioning of auxiliary structures, e.g. parts of the facility on the surface;*
- *Environmental remediation as required;*
- *Programs for monitoring and surveillance,*
- *Programs for security and safeguards;*
- *Plans for preserving knowledge and records about the waste disposed of and the disposal system.*

Delicensing and Ending the Period of Responsibility

5.99 Expectation is that the GDF will be delicensed once licensable activities cease – ie disposal activities and handling of nuclear matter – and that risks from the nuclear hazard (ie waste) are reduced such that nuclear regulation is no longer deemed proportionate to the remaining risks.

5.100 This is likely to be once the underground vaults and tunnels are sealed and the GDF closed with completion of surface facility decommissioning such that regulation by ONR under the licence is no longer necessary – institutional control may be taken over by HSE in conjunction with the relevant environment agency.

5.101 The current criterion for ending the period of responsibility is drawn from Section 5(15) to NIA65 and requires there to be 'no danger' from ionising radiations from anything on the site, as explained in HSE/ONR guidance [27, 28].

5.102 For the case of a GDF, ONR considers that providing the licensee can demonstrate the GDF has been designed, constructed and operated such that the intent of the facility has been met – ie isolation of the waste from the biosphere – as shown by the safety envelope for the post-closure phase, then the licensee should be able to justify and establish that the delicensing criteria are met and thus end the period of responsibility under the nuclear site licence.

5.103 The relevant environment agency is a statutory consultee for delicensing decision making, ensuring that appropriate consideration of environmental issues is taken into account, including post-closure safety for the case of a GDF.

Security challenges posed by a GDF

5.104 The Security Assessment Principles (SyAPs) [29] provide the essential foundation for the introduction of outcome focussed regulation for all constituent security disciplines: physical; personnel; transport; and cyber security and information assurance. Outcome focussed regulation allows greater flexibility in approach and encourages innovation in security solutions that provide effective and robust protection against the modern threat environment.

5.105 ONR does not consider that there are any security considerations specific to a GDF that require additional guidance beyond that which is provided in the SyAPs and supporting nuclear security TAGs [30].

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7. ACRONYMS

ACoP	Approved Code of Practice
ADB	Fire Safety: Approved Document B
ALARP	As low as reasonably practicable
BTS	British Tunnelling Society
BS	British Standard
CDG	Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009
CoRWM	Committee on Radioactive Waste Management
EA	Environment Agency
GDF	Geological Disposal Facility
GRA	Guidance on Requirements for Authorisation (EA/NRW/NIEA)
HAW	Higher Activity Radioactive Waste
HLW	High Level Waste
HMIM	Her Majesty's Inspectorate of Mines
HSE	Health and Safety Executive
HSWA	The Health and Safety at Work etc Act 1974
IAEA	International Atomic Energy Agency
ICE	Institute of Civil Engineers
ILW	Intermediate Level Waste
ITA	International Tunnelling Association
LC	Nuclear Site Licence Condition
LLW	Low Level Waste
NIA65	Nuclear Installations Act 1965
NIEA	Northern Ireland Environment Agency
NMAC	Nuclear Material Accountancy and Control
NRW	Natural Resources Wales
PSR/PRS	Periodic Safety Review / Periodic Review of Safety
PSSR	Pressure Systems Safety Regulations 2000
RGP	Relevant Good Practice
SAP	Safety Assessment Principle(s) (ONR)
SFAIRP	So far as is reasonably practicable
SRL	Safety Reference Level (WENRA)
SSC	Structure, System and Component
SyAP	Security Assessment Principle(s) (ONR)
TAG	Technical Assessment Guide(s) (ONR)
TIG	Technical Inspection Guide(s) (ONR)
WENRA	Western European Nuclear Regulators' Association