KVU - Handling of Norwegian Spent Fuel and other Radioactive Waste

Task 5: Protection of the Environment, Natural Resources and Society

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1 Introduction and Method

1.1 Purpose

Task 5 aimed to examine the requirements for store design and localisation from the perspective of protection of the environment, natural resources and society, including security implications. Task 5 therefore overlaps with Task 4, because the environmental impacts associated with the different sites, and the storage solutions relevant to each site, need to be compared before the best site and associated storage solution is recommended. Similarly, Task 5 overlaps with Task 3, as the different storage and building concept options will present different advantages and disadvantages from the perspective of the topics covered in this Task. Therefore, the contents of this Task:

- Examine minimum requirements for ensuring adequate protection of the environment, natural resources and society;
- Explore the advantages and disadvantages of different localisation, storage and building concept options in order to input to optimisation arguments underpinning options assessments.

The overall assessments of the relevant options are presented elsewhere (Tasks 3, 4 and the overall KVU). The rationale underpinning the ranking of options from the perspective of protection of the environment, natural resources and society, is presented in the following subsections.

1.2 Methodology

The approach undertaken was as follows.

- Requirements from the perspective of international best practice and guidance, and Norwegian legislative and regulatory requirements, were reviewed.
- The main requirements arising from the review were summarised.
- For each of the main requirements identified, an overview of relevant considerations in terms of establishing benefits and disadvantages of localisation, storage and building concept options was produced.
- Specific guidance was then produced concerning assessment of the relevant options against these requirements and associated criteria.

The main part of the analysis concerned requirements for storage of SF and LL-ILW. Arguments were subsequently made concerning the potential extension of the scope to cover also LLW and SL-ILW, and disposal (Section 1.3). For all waste categories, the projected radionuclide inventory discussed in the KVU Task 1 report, and associated waste characteristics, have been considered.

1.3 Scope, Delimitations and Assumptions

In the task analysis, the scope has been broken down in order to consider the following aspects in detail:

- protection of human health and the environment;
- security requirements;
- emergency response; and
- wider social/socio-economic aspects.

This was considered helpful in ensuring appropriate coverage and collating similar classes of arguments. Within each aspect of the scope, relevant sub-topics were considered.

2 Background

2.1 Present Situation in Norway

The present situation is summarised in Task 1 of the KVU. The existing inventory of waste is stored or disposed (depending upon class of waste) at relevant sites in Norway. Environmental impacts are controlled as part of the operational and management regime (e.g. control of aqueous and gaseous discharges) within the Norwegian regulatory framework. Appropriate security arrangements are in place, noting that storage/disposal arrangements are on existing nuclear sites, meaning that security arrangements are shared.

2.2 International Experience and Recommendations

Sections 4.1 to 4.5 summarise international experience and recommendations for each aspect of the scope described above, mapped to Norwegian regulatory requirements. Key points are:

- There are various prescribed basic requirements on safety and security performance that must be met for a facility to be deemed acceptable.
- Beyond that, the principle of optimisation applies; that is, human health and environmental safety (including security considerations) should be prioritised and maximised as far as is reasonably achievable/practicable (ALARA/ALARP). The key is to establish an approach that optimises safety without having disproportionate disbenefits.

For radioactive waste management, this process has been summarised as:

- Considering whether more can be done (in terms of localisation, store and concept options in this case) to protect human health and the environment; and
- Implementing that, unless another option can be shown to have similar advantages without as many disbenefits, or the disbenefits can be shown to be disproportionate to the safety benefits involved.

The aspect of proportionality is explored, consistent with best practice, via the options analysis presented across the reports contributing to the KVU. Note that proportionality considerations include cost (primarily total lifetime cost, but also considering up-front spend requirements; see the cost-benefit analysis) and other aspects e.g. impacts on communities. Assessments of impacts on communities and related aspects overlap with safety and security considerations in that protection of humans and the environment includes protecting communities; also wider considerations are of relevance, including for example local employment opportunities, or transport and infrastructure impacts on settlements. These wider aspects are considered further in the analysis presented below.

3 Conclusions and Recommendations

The main conclusions and recommendations are as follows (summarised from Section 4).

Norwegian law and regulations sets our minimum requirements for safety and security, including aspects such as worker and public dose limits. Moreover, the principle of optimisation (ALARP) applies from the perspective of human and environmental safety, including security. In the task analysis, a summary of requirements from the Norwegian context covering aspects of safety and security and socio-economic aspects, and from international best practice and guidance, is provided.

The outcomes of the analysis against these requirements are summarised below.

Protection of Human Health and the Environment

The review notes a range of relevant considerations here, including:

- worker and public health, including a preference for passive operations and safety, and noting specific requirements for using multiple barriers and performance monitoring;
- impacts on valuable landscapes, natural environments, cultural monuments or cultural environments;
- impacts to species and their habitats, especially endangered or vulnerable species;
- recreational, inland water and marine areas and resources, agricultural land and other resources;
- resource use (energy, materials); and
- facility footprint.

The review also noted the important point that waste treatment and containerisation is an important aspect of any multi-barrier concept; waste forms must be stable, containers must support handling and transport requirements up to the point of final disposal, and together waste forms and containers must contribute to multi-barrier approaches to shielding and minimising environmental releases, thus protecting human and environmental safety consistent with the points noted above. Resource use and the potential for secondary wastes during treatment and containerisation need to be considered in treatment options assessment processes, as they contribute to the overall environmental impacts of the storage strategy. Treatment of unstable SF is considered in Task 2 but treatment of and containerisation of LL-ILW is also important.

These requirements, however, apply whichever localisation and building and storage concept options are followed and do not discriminate between them - except noting that providing barriers through waste forms and containers can reduce the pressure on disposal concepts to provide multiple barriers, and the converse of this which is that high integrity casks might provide robust containment and transport characteristics on their own even if wastes within them degrade.

Having noted these issues, requirements for treatment and containerisation were considered a general point and not pursued further in this aspect of the KVU analysis.

The following key differences between the KVU storage concept options were noted.

- Pool storage concept options have the disadvantage that they require long-term active maintenance of the cooling system and are thus not passive systems.
- Vaults and silos provide passive cooling within an established approach for long-term storage.
- Cask concepts provide the greatest flexibility within a passive safety based approach, with additional benefits from the perspective of minimising accident risks during emplacement.

Similarly, the following comments reflect key differences between the KVU building concept options.

- The basic industry building and surface concrete bunker options will be the easiest to implement and provide the greatest flexibility.
- However underground facilities (e.g. tunnels into hillsides) will provide enhanced passive safety benefits and although there may be a higher up-front cost, the reduction in longer term operational requirements due to the passive safety provided may mean it is the lowest overall cost option despite providing the highest level of safety and environmental protection.

In terms of localisation, there is no reason preventing a store being constructed at almost any locality in Norway that would be able to achieve the required protection of human health and the environment.

Security Requirements

Security encompasses the need to prevent situations in which adversaries could result in the loss of control of radioactive material. This includes both theft and sabotage and the measures that can be taken to recover the situation during an attack. The primary aim of a security regime is to prevent theft or sabotage; once such an act has been undertaken and completed, the situation is in a state of loss of control. Thus aspects such as dispensability, radiotoxicity and the potential impacts of misuse of material after theft or sabotage are considered to be outwith security and are instead "safety" matters (covered elsewhere in this document) except to the extent that such properties of materials may make them more attractive for misuse, and hence increase the likelihood of certain types of attack.

IAEA (2013) cites 12 essential elements of an adequate security regime. Those of most relevance to intermediate store options are as follows:

- identification and assessment of nuclear security threats, targets and potential consequences;
- detection of nuclear security events; and
- planning for, preparedness for, and response to a nuclear security event.

Norwegian law and regulations (e.g. Norwegian Government, 2000) require that assessments and plans underpinning the security, safety and associated emergency preparedness strategies should:

- take all reasonable steps to avoid or reduce the likelihood of such events;
- protect the radioactive sources against theft, sabotage and fire and water damage.

The KVU process identified the following overall key priorities for security measures for stores.

- To protect against "internal" threats that might be realised within the site boundary (e.g. sabotage), and those that might originate outside the site boundary (e.g. civil protests).
- Design basis events within these categories include theft of material, insider sabotage (with potential for radiological releases) and the use of weapons (note that the threat of an attack can lead to impacts, even without any intent of actual attack).
- Aircraft impact is an example of an event normally considered "beyond design basis".

On the basis of the above, the task analysis concluded that, from the perspective of security there are no clear differentiators between the generic localisation options. It is equally plausible that security requirements can be met at any of the locations. Locating stores at existing nuclear sites may offer some advantages in terms of sharing security service arrangements, but that is largely a cost implication rather than an explicit security-related benefit.

Key differences between storage concept options include the following.

- Options involving multiple barriers to wastes and SF, such as emplacement within vaults within the floors of rooms in the storage system, or within casks, will give greater protection against threats and attacks than forms of storage where the material is more readily accessible.

- For pool-based systems, threats or accidents that compromise one element of the system may compromise the entire inventory (e.g. by loss of active cooling).
- Cask-based systems will have the advantage that an incident may only affect one cask at a time. Also, very heavy casks offer a deterrent to theft. They also provide resistance to attack during transport (although transport containers can achieve this for other waste container types).

Key differences between the KVU building concept options were noted as:

- The basic industry building will place the largest burden on active safety arrangements as it does not offer the passive safety benefits of other options.
- Bunker and (in particular) underground options however provide additional isolation of the inventory from a range of threats via passive means.

Emergency Response

The fundamental requirement here is that in the event of an accident or event at a nuclear facility or during the transport of a nuclear substance which entails an imminent threat to public health or the environment, the agency responsible for nuclear accident preparedness or the Norwegian Radiation Protection Authority shall ensure that the population immediately receives information enabling steps to be taken to prevent or reduce damage. Agencies assigned functions in the field of nuclear accident preparedness are required to act according to a coordinated body of plans. Assessments and plans underpinning the security, safety and associated emergency preparedness strategies need to take all reasonable steps to avoid or reduce the likelihood of such events, and ensure response plans are in place, underpinned by staff training, exercises etc.

From the perspective of emergency response:

- There are no clear differentiators between the generic localisation options. It is equally plausible that emergency response requirements can be met at any of the locations.

Key differences between storage concept options include:

- Options involving passive safety and security offer advantages; thus the active cooling approach in the pond concept is not ideal, whereas the other storage concepts offer passive cooling. Simple approaches with minimal handling (e.g. vault concepts) will help minimise the risk of accidents and thus emergencies.

Cask options also help reduce the risk associated with accidents by reducing the likely impact of any one event.

Key differences between the KVU building concept options include:

- The underground and bunker building concepts offer increased passive safety and thus emergency response benefits. However they would need to be carefully engineered to support monitoring and adequate emergency response plans.

Social / Socio-economic Aspects

International best practice and Norwegian requirements note that a range of aspects are relevant considerations from the perspective of socio-economic aspects, including, for example:

- ensuring at least the same level of protection (safety, security) for future populations as for those that exist now;
- minimising reliance on future generations to actively maintain the facility (burden);
- considering the net economic benefit of the plans for local, regional and national communities (jobs, local investment etc.);
- minimising nuisance and disturbance e.g. road transports through habitations during constructions and operations, noise, dust etc.;
- impacts on amenity e.g. local parks, areas of natural beauty, resources used for recreation, etc.;
- visual impacts;
- perceptions of impacts by association with a radiological facility;
- impacts on or indeed benefits to local infrastructure;
- changes to the makeup of communities; and
- impacts on local monuments, areas, resources or buildings of special cultural or historical interest.

All of these challenges will apply to any of the localisations, storage and building concept options for SF and LL-ILW storage. They are important but in the main are not discriminators at this level of analysis. That is:

- In broad terms, social and socio-economic characteristics of sites where there is a pre-existing nuclear industry presence will differ from those where there is no such presence. The storage and building concept options may be more readily accepted than in locations without such industries as a result of familiarity with the issues. However, it is important that social and socio-economic aspects are explored directly with the local population for a particular site, e.g. as part of a subsequent siting process.

- The main potential differentiator between storage and building concept options concerns the underground and bunker building options, both of which offer passive safety and thus reduce burden on future generations. However, this needs to be balanced against the potential lower long-term socio-economic benefit (increased passive safety may mean fewer local jobs).
- Visual impact may be considered an issue for surface facilities if within "line of sight" of local populations or amenities.

Monitoring

An important consideration in developing future plans will be a monitoring strategy. The key safety, environmental protection and security functions described in the above text need to be underpinned by monitoring demonstrating continuing safety and enabling action to be taken if any risks or issues are identified. Key aspects of the monitoring plan will include, for example (see Section 4.6 for more detail):

- monitoring of the wastes and/or spent fuel and container to identify any changes in status and to check that any changes are within the range expected (e.g. reduction in radioactivity and heat output with time);
- monitoring of the waste and/or spent fuel containers to ensure they continue to provide the shielding / containment functions for which they were designed;
- surveillance of facility and monitoring equipment to ensure it continues to provide the required functions including ensuring emergency response-relevant equipment is maintained in case of an event;
- monitoring of workers including protective equipment, clothing and the workers themselves to confirm sufficient radiological protection;
- monitoring of physical aspects of the store building including designed physical safety barriers and security functions;
- monitoring and accountancy to confirm any discharges are within permitted levels and are as expected;
- environmental monitoring including air, surface waters, surface plants and animals, and subsurface resources (e.g. groundwater) to demonstrate that discharges and other impacts are not having a deleterious impact on the environment;

- security monitoring;
- quality assurance and analysis; and
- maintenance of Safety Cases (including Periodic Safety Reviews).

Monitoring will be required whatever the concept and locality chosen. The majority of the requirements will be common to all options, and any differences will reflect specific concept- or locality-specific human or environmental safety or security issues. On this basis any relevant differentiators are already covered in those previous discussions.

In terms of treatment options, stabilisation / conditioning of wastes and spent fuel will help reduce, to some extent, the level of monitoring required during storage, as the condition of the materials with time will be more predictable. However the main common requirements of monitoring regimes will remain.

Extension to Consideration of Storage of LLW and SL-ILW

Similar principles apply to storage of LLW and SL-ILW. However, arguments on optimisation and proportionality need to reflect the nature of the hazard being protected. Although LLW and SL-ILW volumes will be larger than for SF and LL-LLW, the intrinsic hazard per unit volume is much smaller, and none of the wastes will be heat generating. For example, the KVU Task 1 report presents a simple analysis of the Norwegian radioactive waste inventory which differentiates the wastes in terms of the dose rate from the waste packages. Any discharges will also be lower in activity for similar management arrangements, and they will be much less attractive to those who might plan malicious acts or theft.

The extension to consideration of these additional wastes does not substantially affect localisation discussions, given the arguments discussed above that all localisation options are already plausible for higher activity wastes. For storage concept options, it is notable that these wastes will not require active or passive cooling, making (for example) pool options redundant for this category of wastes, whether co-located with SF and LL-LLW or located at different facilities.

LLW and SL-ILW facilities in other countries utilise a range of building concept options, and storage concepts worldwide are almost all based upon surface concepts; even for disposal (see below) some concepts use surface or near-surface approaches, although others use deeper facilities. This again reflects the hazard associated with the wastes and that while the principle of using passive multi-barrier concepts remains, the balance of arguments in terms of benefit and cost and other detriments is more finely poised.

Cost is not considered in this section (it is instead dealt with elsewhere). Noting that, the arguments for storage and building concept option ranking and preference from the perspective of **protection of human health and the environment** do not change for these waste types. However, the relative value of the benefits associated with more complex options is reduced compared to those for higher intrinsic hazard wastes.

Similar arguments apply to the extension of **security requirements** to options involving LLW and SL-ILW. While in principle the same ranking arguments apply, given that these wastes are much less attractive to malicious acts and the implications of accidents will be much reduced, the value of the benefits of more complex options may be even further reduced. The only exceptions to this argument concern the potential for higher inventory SL-ILW packages at the beginning of decay-storage, as accident implications of miss-handling certain SL-ILW packages will be higher at that point than after a few decades of decay.

As noted elsewhere, many LLW stores and repositories operate on the surface with only a site fence and a handful of employees providing security protection, whereas SF is usually stored in secure buildings with a higher degree of active and/or passive protection.

Statements along similar lines can also be made for **emergency response** aspects.

Differences associated with **social / socio-economic aspects** will largely reflect the increased volumes involved, which could (for example) lead to enhanced visual impact for surface repositories. There could potentially be enhanced disruption (or increased need for improvements to infrastructure) locally to deal with increased volumes for transport, but that is not a discriminator between options, rather a common factor across them. It is also possible to argue that lower hazards imply fewer burdens on local communities, and perceptions of impact will be lower. This is borne out by observations that very low-level and low-level radioactive waste storage and disposal facilities worldwide do not attract the level of interest from stakeholder groups that those for higher activity wastes often do.

In addition to the above points, it is important to recognise that again waste treatment and containerisation provide an important role in multi-barrier concepts protecting human and environmental safety for LLW and SL-ILW. As discussed by the KVU Task 1 report, wastes associated with these categories are more likely to be heterogeneous, covering a range of decommissioning and operational wastes, and to include a higher proportion of degradable organics (e.g. cellulosic overalls, structural wood, oils) than in other categories. Therefore although the intrinsic hazard per unit volume is low, given the larger total overall volume and the variety of wastes for different forms of treatment, this is an important consideration. In particular, allowing wastes to degrade in-situ can present challenges if long-term storage options are followed and there may be a requirement to subsequently transport them to a final place of disposal.

Strategies for LLW and SL-ILW treatment in other countries implement the Waste Management Hierarchy including reducing volumes for storage and final disposal as well as ensuring waste form stability. For example, in the UK, incineration and metal decontamination treatments provide an important part of the strategy (LLWR and NDA, 2011; Paulley, 2014), including co-incineration of organic wastes with bulk hazardous wastes in standard commercial incinerators that is relatively cost effective (as all wastes include naturally occurring radioactivity, standard incinerators are typically authorised by regulators to produce wastes up to a certain level of activity, and by co-incineration with bulk wastes the final residues are typically very low in activity). However, the UK situation is driven by the large volumes of future wastes expected and the limited capacity at the UK's main LLW repository. This is not the case for Norway. Nevertheless to ensure handling and passivation requirements waste treatment options will be an important component of future plans, even if no or minimal treatment can then be justified. However, as for SF and LL-ILW, the treatment and containerisation will typically be independent of the localisation, building and storage concept options process, except to note again that high-integrity casks might reduce the need for treatment by providing a robust barrier and transport container even if the wastes within them degrade.

The main change to **monitoring requirements** if these other wastes are considered reflects the additional effort required to monitor a larger amount of wastes, and recognition that different sorts of wastes may require slightly different monitoring techniques or schedules. Monitoring of store buildings will tend to be based upon the most active wastes within those stores, and so there may be some cost benefit to separately locating lower hazard wastes (even if they are still stored on the same site) to help justify applying a proportionately lower level of monitoring effort to those wastes.

Extension to Consideration of Disposal (of SF and LL-ILW)

For disposal, certain criteria are subject to additional emphasis. All the requirements for storage still apply, as disposal is effectively the same as storage until the site is closed and active management ceases. At that point, however, it is only passive safety measures that remain to isolate the wastes and protect people and the environment. In addition, if wastes still require cooling, only systems whereby passive cooling can be relied upon without human operation or maintenance are suitable. These aspects do not affect localisation options for the arguments above (i.e. it is feasible that any concept could be constructed at almost any location in Norway). The focus is therefore on storage and building concepts.

Specifically, concepts such as pool cooling systems are not relevant to disposal, although it is plausible that pools could be used for active cooling during storage, prior to removal at the end of the storage period, with the concept then being converted to a disposal concept or wastes removed to a separate place of final disposal.

More broadly the need for passive approaches for **protection of human health and the environment** and **security requirements** leads to additional emphasis on multiple barriers and isolation. This additional emphasis is often to the extent that internationally subsurface building concepts are usually preferred and surface disposal concepts for SF and LL-ILW are normally screened out for consideration at an early stage. In particular the passive safety provided by the rock overlying an underground facility (the geosphere) provides both isolation and migration barriers to impacts, as well as reducing opportunities for inadvertent or planned human access. Aspects related to operations, monitoring, and accident prevention are unchanged for the arguments associated with stores, again reflecting the attitude that disposal concepts are just storage concepts with no intention to allow retrievals at the point of closure.

For disposal, an important further point is the additional requirements on waste treatment and containerisation to provide barriers to release in the longer term. The waste form and container are normally considered barriers to releases in the multi-barrier concepts and this is an important consideration in optimisation considerations. This is an extension to the equivalent statements for storage in that these barrier arguments also then need to contribute to confidence in passive safety in the longer term.

Disposal and the potential to include non-retrieval concepts brings with it additional storage and building concept options. As noted elsewhere in the KVU and in sources such as IAEA (2009), the use of deep, wide boreholes for disposal of small volumes of higher activity wastes has been practiced in certain countries including the US. Furthermore, borehole disposal concepts for disused sealed sources are under development in Ghana, Malaysia, the Philippines and Brazil as part of an IAEA initiative. Such approaches would also provide the passive safety and isolation benefits of sub-surface concepts such as tunnels, but there would be no possibility of retrieval.

Addition of disposal to the scope also leads to consideration of additional hybrid storage and building concept options. One is noted above, i.e. conversion of pools to storage rooms/tunnels. Others include storing in one building (e.g. until initial peaks in decay heat and the requirements for its management subside) followed by disposal in another. For example, storage in a near-surface or surface bunker could be followed by disposal in wide deep boreholes. Indeed, non-heat-generating LL-ILW could be disposed immediately underground and heat-generating SF later. From a safety and security perspective, the main downside to this class of hybrid options reflects the disadvantages associated with any multiple handling and the associated increased worker dose exposure durations and the potential for accidents including conventional safety concerns.

More generally, LL-ILW and SF might be disposed of using two different concepts at the same or different locations. This could again reflect the extra requirements of heat-generating wastes and the need for passive heat management for those wastes. However, it is likely that for Norwegian wastes, heat generation will not be a major issue.

From the perspective of passive safety and security, however, a range of these disposal hybrids are plausible and likely to deliver the required performance without offering significant disbenefit from a safety and security perspective, if multiple handling is minimised. That is, several potential hybrids offer the potential to co-dispose of SF and LL-ILW at the same location using common infrastructure arrangements (e.g. surface access to subsurface facilities) without compromising passive heat management, safety or security arrangements for either category of wastes.

The extension to disposal does not make a substantial difference to the assessment of **emergency response** requirements, except to note that early non-retrievable disposal options whilst potentially minimising the risk of certain threat scenarios do also prevent emergency responses associated with removal of wastes. However, it is typically argued that using passive safety to minimise the risk of safety or security threats compensates for the reduced ability to respond to such threats.

Extension to disposal does not materially affect many of the **social / socio-economic** aspects considered under storage; similar concepts are employed in broad terms, similar volumes etc. However, whilst disposal might have the perceived benefit of "finally dealing with the problem" to some stakeholders, the perception of risk associated with having waste permanently disposed with no option to retrieve may present difficulties. This can only be dealt with through a well-planned centrally organised siting and engagement process consistent with best practice. This aspect is beyond the scope of this technical task, but recommendations for the next phase are made in a later section of the KVU.

In terms of **monitoring requirements** mapped against the above safety, environmental and security considerations, during operations similar monitoring requirements will apply as they do for stores. However, there will be additional requirements to monitor the environment and characterise environmental features and processes such as groundwater levels and flows, background contamination, rock types etc. both in advance of constructing the disposal system and during operations. This is necessary to help demonstrate long-term passive safety of the disposed system once disposal operations and then at some point subsequently all forms of institutional control have ceased. Monitoring and characterisation for site selection, concept development and construction is likely to be a significant undertaking. This issue is discussed in more detail in Section 4.7 of the KVU Task 4 report (Metcalfe et al., 2014),

Monitoring of the engineering performance including monitoring for a period of time after cessation of operations and system closure will also be important as part of this process. However the effort required should be proportionate to the hazard and the total inventory of radioactive materials is not large by international standards, and so such monitoring may not represent a major undertaking, even if the totality of sustained annual costs with time needs to be taken into account.

Extension to Consideration of Disposal of LLW and SL-ILW

Similar themes apply here; passive safety is important for disposal, but the intrinsic hazard per unit volume is lower for LLW and SL-ILW (in the latter case, in particular after initial decay storage periods) than for SF and LL-ILW. Thus, some nations dispose these categories of wastes to surface repositories, typically planning to emplace impermeable caps at or before closure to minimise infiltration and to provide a long-term passive intrusion barrier. It is also noted that it is generally considered to be good practice to dispose of LLW and SL-ILW as soon as is practicable, without a period of storage. This reflects the limited benefits of radioactive decay and the absence of any other waste characteristics that benefit from a period of storage.

On this basis, the above discussions on disposal also apply to this category of wastes, but the value of ensuring post-closure passive protection again needs to be considered in light of the reduced intrinsic hazard being protected, and the larger volumes that will require management. That is, the differentiators are similar, but the differences in the extent of safety and security performance are reduced consistent with the differences in hazard.

Therefore a range of hybrid schemes (e.g. near-surface LLW disposal, deeper SL-ILW and SF and LL-LLW disposal) are all plausible and could all meet requirements for protection of human and environmental safety, security, emergency response and socio-economic aspects.

Again, part of the strategy for passive safety in the longer-term will rely upon treatment and containerisation options that are not considered in detail here. The extent of the importance of such approaches is related to the lower hazard per unit volume, but on the other hand as noted under the storage discussions above, these wastes will typically be more heterogeneous and contain more degradable organics than some other higher activity wastes, and so the approach to treatment and containerisation needs to be considered carefully in order to provide appropriate confidence in longer-term safety.

4 Task Analysis

4.1 Overview of Requirements for Protection of the Environment, Natural Resources and Society

4.1.1 Basis of Approach

Protection of human health, the wider environment, and associated natural resources and socio-economic concerns are fundamental principles underpinning radioactive waste management including the location and design of storage facilities.

The store must be constructed and operated in such a way as to protect site workers and the general population, the surrounding environment, natural resources and wider society. In practice these requirements mean that all impacts from the facility must be sufficiently small as to meet all regulatory requirements and result in a broad acceptance by stakeholders that the impacts are as low as reasonably achievable.

Norwegian law and regulations (e.g. Norwegian Government, 2000) are consistent with recommendations from international best practice in this area. Two key requirements are notable:

- Impacts including (but not limited to) radiation doses to humans and the environment should be as low as reasonably achievable (i.e. should be optimised to minimise impacts, other factors such as technical practicability and cost also being taken into account).
- Impacts should not exceed certain limits, including a dose limit to any member of the general population of 1 mSv/yr from credible exposure scenarios, and 20 mSv/yr to workers for normal working situations (although higher limits for shorter durations can also be argued on the basis of regulation).

Other impacts on the environment (e.g. impacts to non-human environmental receptors and resource use) are also of interest from the perspective of regulation and decision-making.

In practice, this means that:

- Optimisation (that is, minimisation) of impacts to human health and the environment is a key consideration across all aspects of siting, design and operation of a radioactive waste or SF storage facility. Optimisation is typically demonstrated by ensuring these impacts are core considerations in options processes for each of these aspects, implementing the principle of ALARA (as low as reasonably achievable). Normally, protection of health and the environment is weighted highly in such options processes, as international guidance and best practice indicates the lowest safety risk option should normally be adopted unless the costs or other practicability concerns show clearly it would be disproportionate and thus impracticable to do so.

- It is necessary to provide confidence, in advance of constructing a store, that the performance of the store will at a minimum meet the dose limit and other requirements set out in regulation. Given the principle of optimisation noted above, typically projected impacts from stores will be lower than this target.

These requirements have been addressed in the KVU process as follows.

- The main requirements for protection of human health, the environment, natural resources and society are described.
- Elements of the KVU process evaluating options for localisation and concept design are analogous to the options processes required to demonstrate optimisation from a regulatory and best practice perspective. Therefore, the following sections provide supporting information that is used elsewhere in relevant Tasks of the KVU.
- Arguments for the safety of the preferred options that are analysed during the KVU process are presented separately to provide confidence that safety targets can be met, or that future work is likely to be able to show that these safety targets will be met.

4.1.2 Summary of Requirements

In what follows, an overview of regulatory and international best practice requirements in this area is provided, focussing on the implications for store design and operation arising from the primary requirement of protecting humans and the environment.

IAEA (2011a) provides a helpful list of requirements that the localisation, concept and waste form/container, and operational arrangements together need to meet for SF storage. The requirements for long-lived ILW will be similar in broad terms (see IAEA, 2006), except the nature of wastes means arrangements may be different, and in particular heat generation will be much less of an issue. The requirements are summarised in Box 1. These aspects of design are necessary to demonstrating optimisation (ALARA/ALARP) and compliance with dose limits in demonstrating adequate control of risks and hazard associated with nuclear safety. They therefore represent fundamental aspects of Nuclear Safety Cases that will be required for the final store.

Such a Safety Case will require an assessment of safety covering not just the expected performance of the system but also fault/failure scenarios. In that context, the safety assessment “hazards” referred to in Box 1 will include accidents during operations (e.g. leakage, canister drops during emplacement etc.) and explosions, system failures, fires, and natural events such as earthquakes etc.; assessments will need to show that these scenarios are very unlikely to occur and/or the system design is robust and proportionate to the hazard these scenarios represent (that is, the risks are tolerable and ALARA/ALARP).

The focus of these requirements is on the main safety functions required to deliver containment, and thereby protection of humans and the environment. Whilst these are the primary and over-riding requirements for storage concepts, other issues are also important in options selection for storage facilities, such as the environmental impact associated with implementing and operating the store, and local socio-economic impacts (e.g. impact on employment etc.).

A further aspect to note is that these requirements are focussed on the store itself. Other facilities such as waste receipt and buffer storage areas are likely to be required at a store site. However, as the volumes of Norwegian SF and long-lived ILW are not large (see the KVU Task 1 report) these facilities are not likely to be overly large or complex. Also, they will be common features of all the storage localisation and concept options.

Each aspect of requirements is discussed in more detail in the following sections.

Box 1: Summary of Requirements for Storage (after IAEA, 2012)

Although designs of SF storage facilities may differ, in general they should consist of relatively simple, preferably passive, inherently safe systems intended to provide adequate safety over the design lifetime of the facility, which may span several decades. The lifetime of a spent fuel storage facility should be appropriate for the envisaged storage period. The design should also contain features to ensure that associated handling and storage operations are relatively straightforward.

In general, the storage facility should be designed to fulfil the main safety functions, i.e. maintaining of subcriticality, removal of heat, containment of radioactive material and shielding from radiation and, in addition, retrievability of the fuel. The design features should include the following features:

(a) Systems for removal of heat from the SF should be driven, if possible, by the energy generated by the SF itself (e.g. natural convection).
(b) A multibarrier approach should be adopted in ensuring containment, with account taken of all elements, including the fuel matrix, the fuel cladding, the storage casks, the storage vaults and any building structures that can be demonstrated to be reliable and competent.
(c) Safety systems should be designed to achieve their safety functions with minimum need for monitoring.
(d) Safety systems should be designed to function with minimum human intervention.
(e) The storage building, or the cask in the case of dry storage, should be resistant to the hazards taken into consideration in the safety assessment.
(f) Access should be provided for response to incidents.
(g) The SF storage facility should be such that retrieval of the SF or SF package for inspection or reworking is possible.
(h) The SF and the storage system should be sufficiently resistant to degradation.
(i) The storage environment should not adversely affect the properties of the SF, SF package or the storage system.
(j) The SF storage system should allow for inspections.
(k) The SF storage system should be designed to avoid or minimise the generation of secondary waste streams.

Security and access controls are required at SF storage facilities to prevent unauthorised access by individuals and the unauthorised removal of radioactive material, and such controls should be compatible with the safety measures applied at the facility.

4.2 Protection of Human Health and the Environment

4.2.1 Overview of Requirements for Protecting Human Health

The requirements listed in Box 1 are all focussed on minimising the risk of releases of radioactivity to the local and wider environment, and thus on protecting the health of facility workers and the wider public.

The arrangements employed need to be proportionate to the hazard posed by the SF and other wastes to be disposed. For the Norwegian situation, it is worth noting that while for SF the hazard per unit volume of fuel is high compared to other ILW and LLW wastes, the total quantity is small (c. 17000 kg; see the KVU Task 1 report). Therefore, arrangements for protection of that hazard may be much less complex than for other countries with more significant volumes of SF, and their equivalent arrangements for addressing the requirements in Box 1.

The fundamental requirements for a Norwegian SF and/or long-lived ILW store can be summarised as follows:

- The store design will need to demonstrate appropriate shielding to prevent worker and public exposure to radioactivity.
- For SF, heat management will be a fundamental aspect of the design.
- Criticality avoidance is also essential.
- The multi-barrier concept is key. The store design should not be reliant on any one barrier for shielding and more generally for the prevention of releases.
- The concept should rely on passive safety as far as possible. It is a general principle of radioactive waste and SF management arrangements that passive safety is to be preferred, and in particular the longer a store is intended to be used for, correspondingly less reliance should be placed on active management relying on operators to provide safety measures.
- The ability to monitor stored material and also to retrieve and rectify any issues is an important element of safety arrangements.
- Potential accident and fault/failure scenarios that could compromise safety will need to be considered in advance. The design and operational approach should be consistent with minimising the likelihood of their occurrence and providing confidence in the robustness of arrangements to provide safety if they do.

- A Safety Case will need to be prepared in advance of the construction and licensing of a facility showing that it will meet ALARA/ALARP and dose compliance requirements, including adequate consideration of accident and fault/failure scenarios and associated risks.

In addition, the KVU process needs to appropriately consider *conventional* safety risks e.g. in tunnel or above-ground construction, working at height etc. Most likely these aspects are common across options and addressed via standard safety management approaches, but it is important they are not overlooked.

4.2.2 Overview of Further Requirements for Protecting the Environment

The containment requirements described in Section 4.2.1 are also fundamental to protection of the environment during store operation. The additional requirements noted here therefore include wider impacts to the environment during storage building construction and operation. They represent factors normally assessed in any Environmental Impact Assessment (EIA) associated with planning processes for new facilities, and are important secondary considerations for localisation and concept design.

Assessment considerations here include:

- recourse use (e.g. energy, materials) involved in facility construction and operation;
- the footprint of the facility;
- impacts on local sensitive environmental populations (e.g. rare and/or protected plant or animal species);
- any impacts on natural resources (e.g. surface or groundwater resources);
- impact on other resources (e.g. agricultural land quality, tree removal, resources used by other industries such as minerals and geothermal resources);
- impacts on environmental receptors or humans as a consequence of environmental impacts: for example impact on humans due to impacts on land or water quality, crops etc.;
- impacts due to degradation of quality of land with special cultural significance and/or amenity value (e.g. areas of natural beauty and areas utilised for recreational activities); or impacts to water resources including fjords and water courses.

According to Norwegian regulations "significant effects" on the environment are those that in particular could affect the kinds of area listed in Box 2 (from Norwegian Government, 2005). The potential for such effects must be assessed explicitly when undertaking an EIA. Note that in addition to the content of the present section, a number of related requirements are reflected in the discussions on security, emergency response and socio-economic considerations in Sections 4.3 to 4.5.

A key aspect of minimising impacts to the environment during operations concerns ensuring that so-called secondary wastes are minimised and appropriately managed. These wastes are permitted aqueous or gaseous discharges to the environment containing residual radioactivity or other forms of contamination. More broadly, in addition to ensuring human health and environmental protection from unplanned releases through the multi-barrier concept described above, assessing the environmental impact of permitted discharges on potential receptors will be important.

A core aspect of ensuring safety and minimising secondary wastes concerns the waste treatment and containerisation approach. Stable waste forms with suitable containment will help minimise releases of radioactivity during the storage period. The waste forms and container thus provide important contributions to the multi-barrier approach. They can add to or indeed reduce the need for multiple barriers within the rest of the disposal concept. The aims are to:

- Ensure chemical stability and passivation of the waste form, such that it provides containment, including providing shielding and minimising contaminant releases to the environment.
- Minimise future degradation of the waste form during the storage period such that it will still provide a barrier at the end of the storage period.
- Provide confidence that the container will also provide a barrier to radioactivity and contaminant releases across the storage period.
- Ensure the container and waste form within it meets handling and transportation requirements, both during storage and any subsequent removal to final disposal.

These requirements, in terms of requirements for treatment of unstable SF, are reflected in the Task 2 analysis. In addition, the assumption is made here that any LL-ILW will be treated and containerised sufficient to provide containment and handling functions associated with the storage approach. It is noted that in general these requirements apply whichever localisation, building or concept options are selected; they are general requirements that do not have specific implications for individual options and do not discriminate between them. The exception to this rule is to note that high-integrity casks might reduce the need for treatment by providing a robust barrier and transport container even if the wastes within them degrade.

Treatment and container options are not discussed further here. However, the importance of the waste form and container in providing human and environmental safety protection and supporting transport and handling requirements is highlighted as an issue for the KVU as a whole.

Box 2: Criteria for Identifying Environmental and Other Impacts for Consideration in EIA Submissions in Norway (after Norwegian Government, 2005)

Plans and projects pursuant to section 3 shall be dealt with pursuant to the Regulations if they:

(a) are located in or are in conflict with areas with particularly valuable landscapes, natural environments, cultural monuments or cultural environments that are protected or preserved, temporarily protected or preserved of which the protection or preservation has been proposed, or where there are or there is a strong likelihood of finding automatically preserved cultural monuments that are part of a cultural environment that goes far back in time,

(b) are located in or are in conflict with important natural areas on which there has been no encroachment, or pose a threat to directly endangered or vulnerable species and their habitats or to other areas of particular importance for biological diversity,

(c) are located in large natural areas that are particularly important for the pursuit of recreational activities, including forests bordering urban areas, and in important areas close to watercourses that have not been set aside for physical development and in major green structures and important recreation areas in towns and urban areas, and where the plan or project conflicts with outdoor recreational interests,

(d) fall within the scope of the National Policy Guidelines (NPG) for planning in coastal and marine areas in the Oslo Fjord region, NPG for protected watercourses and NPG for coordinated land-use and transport planning and, at the same time, conflict with the purpose of these guidelines, or which conflict with guidelines for the development of shopping centres that have been laid down in county sub-plans,

(e) may conflict with the pursuit of Sami commercial activities in uncultivated areas, or are located in areas of special value for reindeer husbandry or limited seasonal pasture and may conflict with reindeer husbandry interests, or may in other ways conflict with the land-use needs of reindeer husbandry,

(f) entail the substantial reallocation of agricultural, natural or outdoor recreational areas or areas that have been zoned for agriculture and that are of significant importance for agricultural activities,

(g) result in a significant increase in the number of persons who are exposed to high levels of air pollution or noise, or may lead to significant pollution of soil, water and sediments, or entail a risk of serious accidents, radiation, landslides and flooding,

(h) may have consequences for public health due to significant changes in the composition of the population, the housing market, housing needs or the need for services,

(i) may have significant consequences for the population’s access to outdoor areas, buildings and services,

(j) may have significant negative consequences for another state.

4.2.3 Protection of Human Health and the Environment: Commentary on Discriminating Factors between KVU Localisation and Storage Concept Options

The following discussions provides input to (and is consistent with) the options discussions on localisation (Task 4) and concept options (Task 3).

Localisation

A number of localisation options are presented in Task 4. These are generic in nature, covering different kinds of site that may be found in different regions of Norway. From the perspective of human safety and the environment, the following general points can be made, and are reflected in the more detailed Task 4 assessment.

- There is no technical reason preventing a store that would be able to achieve the required protection of human health and the environment being constructed at almost any locality in Norway; any of the localisation options in Task 4 would be viable given sufficient resources to implement an appropriate store concept. That is, achieving safety is not dependent on the local environment. On this basis, most aspects relevant to safety or environmental protection are a function of the concept rather than localisation.
- There may be important sensitive environmental populations, natural resources or other receptors located in the broad regions represented by the generic localisation options. However it is likely that, whichever localisation option is preferred, subsequent planning processes concerning the specific choice of location would be able to avoid those domains and hence any associated impacts.

Storage and Building Concept Options

The storage and building concept options are described under Task 3. Potential differentiators between them from the perspective of human and environmental safety include the following.

- Building and concept options involving multiple barriers to prevent radioactivity escape are to be preferred. However, all of the concepts potentially allow this approach. Nevertheless some offer more robust systems than others. For example, casks provide multiple barriers at all points in the handling cycle, and underground options involve an additional barrier to releases to the environment and public (the geosphere barrier) compared to equivalent concepts located above ground.

- Passive approaches to safety are a significant advantage, including containment and heat management approaches. This argues against active water cooling approaches, for example. Isolation of wastes from access and the environment via storage underground also offers passive safety benefits.
- Passive safety also typically means lower operational resource (e.g. energy) use.
- Simpler storage concept approaches involving fewer steps minimise the likelihood of accidents. Minimising the height of a canister fall in the case of a canister drop incident is also a relevant consideration.
- Minimising the amount of material that might be compromised by the same accident/incident event is also relevant to minimising safety risk. For example, an incident using a cask concept may only damage that one cask, given the structural integrity provided by the casks, whereas problems in a vault, silo or wet store may impact on a larger number of containers.
- Underground facilities may have less surface "footprint" and thus cause less long-term surface environmental disturbance. However they may cause more disruption and more resource (energy) use in construction for equivalent concepts.
- All designs can be implemented consistent with providing the required criticality avoidance controls.

4.2.4 Protection of Human Health and the Environment: Summary of Input to Opportunity Study

On the basis of the above, the following overview comments can be made on key differences between the KVU storage concept options:

- Pool storage concept options (see Task 3) have the disadvantage that they require long-term active maintenance of the cooling system and are thus not passive systems.
- Vaults and silos provide passive cooling within an established approach for long-term storage.
- Casks concepts provide the greatest flexibility within a passive safety based approach, with additional benefits from the perspective of minimising accident risks during emplacement.

Similarly, the following comments reflect key differences between the KVU building concept options:

- ▲ The basic industry building and surface concrete bunker options will be the easiest to implement and provide the greatest flexibility.
- ▲ However underground facilities (e.g. tunnels into hillsides) will provide enhanced passive safety benefits and although there may be a higher up-front cost, the reduction in longer term operational requirements due to the passive safety provided may mean it is the lowest overall cost option despite providing the highest level of safety and environmental protection.

In terms of localisation, there is no reason preventing a store being constructed at almost any locality in Norway that would be able to achieve the required protection of human health and the environment

Full descriptions of relevant elements of the KVU location, concept option and building option comparisons are provided under the Task 3 and Task 4 sections.

4.3 Security Requirements

4.3.1 Overview of Security Requirements

International Best Practice

Security encompasses the need to prevent or mitigate situations in which adversaries could result in the loss of control of radioactive material. This includes both theft and sabotage and the measures that can be taken to recover the situation during an attack. The primary aim of a security regime is to prevent theft or sabotage; once such an act has been undertaken and completed, the situation is in a state of loss of control. Thus the potential impacts that might arise as a result of misuse of material after theft or sabotage are considered "safety" matters beyond security controls (such "safety" aspects reflect those discussed in Sections 4.1 and 4.2). However the inherent characteristics of a concept and associated waste forms that might influence the attractiveness to misuse (including e.g. dispersibility and toxicity of materials) are important considerations in understanding potential modes of attack and establishing proportionate security defences, in addition to being important to safety.

IAEA (2013) cites 12 essential elements of an adequate security regime to do this. Those of most relevance to intermediate store options are:

- ▲ identification and assessment of nuclear security threats, targets and potential consequences;

- detection of nuclear security events; and
- planning for, preparedness for, and response to a nuclear security event.

IAEA (2011b) makes a series of recommendations that can contribute to the overall safety of radioactive waste storage by addressing these key needs. Those related to the location and design of the facility (i.e. in addition to common operational and procedural requirements) include:

- a threat assessment and definition of a Design Basis Threat arising from external or internal adversaries;
- a suitable physical protection system including access controls, surveillance, communication and systems to delay adversaries;
- minimising the number of access points, in particular to protected and vital areas;
- minimising transport time, the number of transports and knowledge of transport schedules and routes.

The requirements most relevant to location are concerned with the presence and nature of threats (e.g. proximity to transport routes or population centres) for the particular location. Also relevant is the proximity to response forces and facilities (e.g. a military base). A further important consideration is the extent to which the location minimises the requirements for transport of the nuclear material.

Specific Requirements for the Norwegian Waste Storage Context

Norwegian law and regulations (e.g. Norwegian Government, 2000) require that assessments and plans underpinning the security, safety and associated emergency preparedness strategies should:

- take all reasonable steps to avoid or reduce the likelihood of such events;
- protect the radioactive sources against theft, sabotage and fire and water damage (as also noted in Section 4.4).

The safety and environmental protection requirements described in Section 4.1 also have significant overlap with security requirements; for example, many passive safety measures (e.g. isolation of wastes through thick caps or geological barriers) also provide passive security benefits. Moreover concepts that are less likely to result in impacts to the environment (e.g. due to the use of robust containers, waste isolation, non-dispersible waste forms etc.) are also likely to reduce the attractiveness of the wastes to misuse, with a corresponding reduction in the likelihood of an attack.

Related requirements for emergency response planning recognising the relevant threats are discussed in Section 4.4.

During the KVU process, discussions were held with a range of individuals with responsibility for ensuring or regulating security matters concerning radioactive materials in Norway (Collier and Metcalfe, 2014). That meeting identified the following overall key priorities for security measures for stores:

- to protect against "internal" threats that might be realised within the site boundary (e.g. sabotage), and those that might originate outside the site boundary (e.g. civil protests);
- design basis events within these categories include theft of material, insider sabotage (with potential for radiological releases) and the use of weapons (note that the threat of an attack can lead to impacts, even without any intent of actual attack); and
- aircraft impact is an example of an event normally considered "beyond design basis".

Associated with these broad priorities a range of supporting objectives are relevant to store design and localisation. These objectives should typically be reflected in options assessments processes as evaluating performance against them will provide the basis for options differentiation from a security perspective.

Concept/Site Supports Active Security

- Generally this means personnel are present to guard the facility. More broadly active security prevents or responds to attempts to access a facility. Some active security during storage is typically required, but how much depends on the balance between active and passive security chosen and the requirements of regulations.[2]
- There is a low "up-front" cost for approaches that rely on active security, but there is lifetime expenditure and commitment.
- The overall security requirements for a SF store-only site are less onerous than for a reactor plus SF store site, but a store constructed at a reactor site would benefit from the existing security arrangements.

[2] It is also noted however that for some low-hazard (and thus low-risk) storage installations abroad (not SF), there is no continuous on-site active presence, with regular monitoring, remote cameras and a response system being installed instead.

- The effectiveness of active security can be assessed (for example) by considering the defined level of attack threat that could be repelled with confidence.

Concept/Site Supports Passive Security

- Examples include fences, the use of natural barriers, and store access arrangements.
- Barriers to access also include keeping a significant distance between the store and a site boundary, so that there is less vulnerability to weapons fired from the site boundary.
- There may be a large initial capital cost for a store with multiple passive barriers, but thereafter there would be maintenance only.
- Passive security would be less likely to fail due to human issues (error, lack of staff etc.) than active security.
- Passive security would be less likely to be a contributing factor in accidental damage than active security (e.g. collateral damage to surrounding property caused by an active response to civil unrest).
- Noting these advantages of passive security measures, a below ground store (cavern or silo) would have some intrinsic security benefits compared to a surface store.
- Some elements of passive security can be achieved by appropriate package design to reduce attractiveness to misuse as well as appropriate store design.
- It might be possible to rate the effectiveness of passive security measures according to the time for which they allow the facility to resist defined intrusion attack or a defined level of attack with weapons.

Perceptions of Security

- Some concepts may appear more vulnerable (e.g. because they are visible), thus encouraging threats or causing concern to a nearby community.
- A new site may be more secure in this regard (depending upon where it is sited), but stakeholders at existing sites may be more likely to accept the same security measures than those associated with "new" sites, if the existing site measures are thereby improved.

Ability to Respond

- Response time is to some extent site dependent.
- An urban site may allow a quicker security / emergency response than a rural site; an urban site would be relatively close to security / emergency services.

However, compared to a rural site, a security/emergency response in an urban setting would cause greater disruption and potentially greater numbers of people would be affected.

- A response to a security-related incident during transport would depend in part on the location of the site and the number and characteristics of transport routes (e.g. multiple transport routes may allow security services to respond from multiple localities; narrow transport routes with "bottlenecks" may provide opportunities for attackers).

Retrievability

- The time to retrieve a SF container may be related to security vulnerability. Packaging and store design (e.g. whether the waste is in free-standing casks or within concrete vaults, weight of waste-filled containers) etc. determine how easy it would be to retrieve waste from a store, thus influencing their attractiveness to theft (and indeed sabotage).
- When ranking options there is a need to balance the ease of retrievability at the end of the defined storage period, and in case there is a need for retrieval for safety/environmental reasons, against the improvements in security that might be offered if retrievability is compromised in part by the barriers emplaced.

Transport Vulnerability

- SF transport is already undertaken routinely.
- The period of transportation is one of relative vulnerability compared to the period of actual storage, albeit only for a short period at the start of a store's life.
- The number of transportation events, the distances transported, and the routes used affect the risk (greater distances, and more transportation events would broadly correlate with increased risk, all other factors being equal).
- Transport through urban areas is not helpful with regard to security.
- Predictable routes are not helpful with regard to security.

Site Characteristics

- Location choices may possibly influence security indirectly. For example, constructing a store on a hill top may make a store a more visible target for attack from distance or from the air; that is the topography has an indirect impact upon security. Another example is that an urban store location may potentially allow attackers more opportunity to come into close proximity to the store.

Consequences of Successful Attack

- When screening / ranking store concept and site location combinations using security-related criteria it is important to assess the potential consequences of a successful attack. That is, there may be smaller potentially adverse consequences for a given kind of attack on some store concept / site combinations than on others. Such potential consequences are related to the attractiveness of the wastes to misuse, and thus the likelihood that adversaries may attempt attacks that could lead to a loss of control.[3]

4.3.2 Security: Commentary on Discriminating Factors between KVU Localisation and Storage Concept Options

The following discussions provides input to (and is consistent with) the options discussions on localisation (Task 4) and building and concept options (Task 3).

Localisation

There are various ways in which localisation options can enhance security protection. However, the relative value of these enhancements is a separate judgement.

As any of the store concepts are capable of being constructed at any of the generic locations, in principle the main security differentiators will be related to concepts, not localities, in particular when considering passive security/safety approaches. In addition, some localisation options may offer additional benefits.

- The period of transport represents a period of relative vulnerability. The ability to vary routes rather than use predictable routes / routines is an advantage. However, the vulnerability will only persist for a relatively short time compared to a store lifetime, even for remotely located stores, so the security advantages of siting a store near the waste producers need to be viewed relative to this factor.
- Sites near centres of population may offer better incident response services and times, although sites within centres of population may cause more disruption if

[3] IAEA (2013) and related guidance is clear that the aims of nuclear security measures are to prevent loss of control in the first place, as after loss of control (e.g. by theft of materials) there are too many potential subsequent misuse scenarios for it to be practicable to fully assess them. Therefore, the priority is to prevent loss of control, applying a level of effort proportionate to the attractiveness to misuse of the materials being affected, and noting also the damage to public confidence that may occur if materials are subject to theft or sabotage.

an event occurs. Transport routes through centres of population are also more vulnerable.

- Large sites where the store is situated a notable distance away from the perimeter will reduce the likelihood of certain forms of attack e.g. weapon-based.
- Stores at raised locations with no line-of-site shielding will present a more "obvious" target than those that are hidden.
- Stores located at the sites of existing facilities will be able to make use of security arrangements already in place, although this may be considered in the main a potential cost benefit.

Storage and Building Concept Options

The main differentiator between options is the extent to which different options provide passive security. With that in mind:

- Concepts with more multiple barriers (active and/or passive) provide additional security compared to those that have fewer barriers to access.
- Underground facilities (or to a lesser extent concrete bunkers) offer passive security and access benefits over surface facilities relying on active measures.
- If the concept means that packages are difficult to retrieve, this will mitigate against theft / removal scenarios.
- Large casks can be difficult to remove (they are very heavy) and difficult to compromise and so can offer passive security benefits in addition to those associated with the building concept.

4.3.3 Security: Summary of Input to Opportunity Study

On the basis of the above, the following overview comments can be made on key differences between the KVU localisation options from the perspective of security:

- There are no clear differentiators between the generic localisation options. It is equally plausible that security requirements can be met at any of the locations. Locating stores at existing nuclear sites may offer some advantages in terms of sharing security service arrangements, but that is largely a cost implication rather than an explicit security-related benefit.

Key differences between storage concept options include:

- Options involving multiple barriers to wastes and SF, such as emplacement within vaults within the floors of rooms in the storage system, or within casks, will give greater protection against threats and attacks than forms of storage where the material is more readily accessible.
- For pool-based systems, threats or accidents that compromise one element of the system may compromise the entire inventory (e.g. by loss of active cooling).
- Cask-based systems will have the advantage that an incident may only affect one cask at a time. Also, very heavy casks offer a deterrent to theft. They also provide resistance to attack during transport (although transport containers can achieve this for other waste container types).

Similarly, the following comments reflect key differences between the KVU building concept options:

- The basic industry building will place the largest burden on active safety arrangements as it does not offer the passive safety benefits of other options.
- Bunker and (in particular) underground options however provide additional isolation of the inventory from a range of threats via passive means.

Full descriptions of relevant elements of the KVU location, concept option and building option comparisons are provided under Task 3 and Task 4.

4.4 Emergency Response

4.4.1 Overview of Emergency Response Requirements

International Best Practice

A number of IAEA publications and other resources cover responses to emergencies at nuclear installation. Perhaps the most helpful in the storage KVU context is IAEA (2011a). This notes that it is important that arrangements are in place at a store to ensure, amongst other requirements:

- Appropriate monitoring of the store is undertaken to identify any significant events or anomalies.
- At least one individual with appropriate training and responsibilities is always available to decide how to respond in the case of an emergency.
- The potential threats and risks (with a particular focus on "beyond design basis" threats not covered by the main scenarios reflected in environmental/safety/security strategies and plans and associated store

designs) should be elicited and impacts estimated. This includes understanding the potential radiological consequences of beyond design basis events including deterministic and statistical impacts to workers, emergency responders and the public. An aspect of this understanding concerns the circumstances under which the risk to emergency responders is too large for them to undertake certain actions or enter certain areas after an event.

- A range of appropriate emergency response services and providers are available to cover credible risks.
- Documented emergency preparedness plans and procedures are in place and facility staff, emergency responders etc. are aware of their requirements.
- Regular emergency preparedness exercises should be held.

Specific Requirements for the Norwegian Waste Storage Context

Requirements from Norwegian Legislation and Regulation

Norwegian law and regulations (e.g. Norwegian Government, 2000) provides specific guidance on requirements for emergency response planning for radiological facilities in Norway.

The fundamental requirement is that in the event of an accident or event at a nuclear facility or during the transport of a nuclear substance which entails an imminent threat to public health or the environment, the agency responsible for nuclear accident preparedness or the Norwegian Radiation Protection Authority shall ensure that the population immediately receives information enabling steps to be taken to prevent or reduce damage. Agencies assigned functions in the field of nuclear accident preparedness are required to act according to a coordinated body of plans.

Assessments and plans underpinning the security, safety and associated emergency preparedness strategies need to:

- Take all reasonable steps to avoid or reduce the likelihood of such events and protect the radioactive sources against theft, sabotage and fire and water damage (as also noted under Section 4.3).
- Give the employees the necessary information and training as well as the protective equipment needed to limit exposure to radiation in connection with such events.
- Prepare an emergency preparedness plan which describes measures to halt, limit and remove discharges, measures to limit radiation doses and other measures to reduce the consequences of such events.

- Hold exercises.

The emergency preparedness plan should detail notification routines, organisational arrangements and responsibilities, pre-planned routines for handling given situations, routines for identifying the scope of an event, communication routines, description of relevant protective equipment and procedures for follow-up of involved personnel, procedures for information to the population etc.

The legislation and regulations also reflect that rescue work should aim to limit exposures to rescue workers to the normal dose limits for radiological workers, and describes special circumstances under which emergency response workers may agree to risk receiving higher doses in order to achieve control and protect human lives.

Requirements Arising from Best Practice in Norway

In addition to the group discussions on security outlined in Section 4.3, the same workshop considered good practice in emergency preparedness planning (Collier and Metcalfe, 2014). The discussions shared some of the main themes and priorities with the security considerations, and identified the following additional objectives with a particular focus on beyond design basis safety or security risks. As for the security equivalents, these objectives should typically be reflected in options assessments processes as evaluating performance against them will provide the basis for options differentiation from an emergency preparedness perspective.

Ability to Respond

- The response time will be to some extent site dependent.
- Urban sites may allow quicker security / emergency responses but also there could be greater disruption and potentially larger numbers of people could be affected.
- There are already emergency response experts on-site and procedures at existing sites, but new sites would need on-site expertise and procedures to be established.
- The response to a transport emergency would depend in part on the location and the characteristics / lengths of transport routes.
- Emergency escape from and access to store areas would be an important factor influencing emergency responses.

Vulnerability/Likelihood of Natural Hazards

- Hazards include fire (inside and outside), flood, landslip/rockslide etc.
- Also power or communications loss could cause or contribute to an emergency situation.

- Passively safe systems, with minimum handing operations etc. are less likely to result in emergencies than systems that require action to ensure safety.

Vulnerability to Structural Failures

- Factors leading to uncertainty or failure could be used a basis for screening / ranking sites and designs.
- The consequences of structural failure should be explored when screening / ranking designs.
- Robust proven designs might be preferred over new designs. In the former case there would be an established safety record and emergency response procedures would be well understood. There might be greater potential for things to go wrong should a new design be implemented.

Potential Hazards from Neighbouring Facilities

- Neighbouring activities / facilities should be taken into account when screening / ranking sites from the perspective of emergency preparedness.
- The potential for an accident at a neighbouring facility to cause an emergency situation at the waste store should be considered.
- Conversely, the possibility that the consequences of an emergency at the waste store might depend upon the nature of adjacent facilities and activities should be considered.

Vulnerability to Transport Failure

- Road accidents are the most likely issue of concern. The worst case is that an accident could cause a partial loss of shielding through cask/container damage. However, the likelihood of this occurring is very small because transport casks are designed to withstand collisions and fire.
- Errors in loading / securing casks/containers may potentially give rise to an emergency situation, although again the probability is judged to be very small.
- Road load / access route constraints may impact upon the probability of a road accident and the severity of the consequences should one occur. For example, it might be more difficult to respond to an accident that occurs in a narrow road tunnel than to an accident that occurs on a wide open road. An accident that was to occur in an urban area might be expected to have a higher probability of severe consequences than an accident that occurs in a rural area.
- Breakdown response has been considered, but is not considered to be a major risk.

Challenges to Clean-up

- The nature of the area surrounding and store, including the characteristics of flora, fauna, water resources and human activities within the area, would impact upon the ease with which the consequences of an emergency could be mitigated.
- The population density could impact upon the response to an emergency, whether at the store itself, or adjacent to a transport route.

4.4.2 Emergency Response: Commentary on Discriminating Factors between KVU Localisation and Storage Concept Options

The following discussions provides input to (and is consistent with) the options discussions on localisation (see Task 4) and building and concept options (Task 3).

Localisation

Given the generic nature of the localisation options, there is limited reason to differentiate between any of the options on the basis of emergency preparedness. For each of the broad regions reflected by the generic options, it will be possible find a suitable site that will enable arrangements to be made that satisfy emergency preparedness and response requirements.

However, in broad terms, it also worth noting that:

- The most vulnerable period is during transport operations; this applies to security considerations, but also to accident (e.g. traffic accident or handling) risks. However the limited volume of wastes to be transported means that the overall risk is likely to be low.
- Locations nearby population centres will be of assistance in assuring emergency provision. However the overall response will depend upon the specific nature of emergency access routes.
- Locations close to or within population centres however will involve the (most likely small) risk of local populations being impacted by any event, and there may be disruption (traffic confusion etc) that could affect any response.
- Risks associated with impacts from other neighbouring facilities on the store, or the impacts of the store on neighbouring facilities (e.g. in the event of an emergency) are relevant.

- The local environment may also influence the nature and extent of any mitigation actions employed after an event.

Storage and Building Concept Options

The main differentiator between options is again the extent to which options provide passive safety and security. This is because:

- Stores with a high degree of passive safety are less susceptible to accidents associated with human error. This includes store and transportation concepts that minimise handling activities.
- However concepts such as below-ground stores with a small number of entrances, whilst providing safety and security advantages, may limit the ways in which emergency response can be provided.
- Stores with inherent structural safety will minimise the risk of collapse e.g. following a landslip or seismic event.
- Known, mature concepts are more likely to be successfully designed so as to minimise accident risk.
- Underground building concepts or complex near-surface or above-ground approaches could involve barriers that are required for security but could plausibly hinder effective monitoring and retrievals to prevent or deal with emergencies. However there is no reason why these issues can't be satisfactorily addressed by the facility design.

4.4.3 Emergency Response: Summary of Input to Opportunity Study

On the basis of the above, the following overview comments can be made on key differences between the KVU localisation options from the perspective of emergency response:

- There are no clear differentiators between the generic localisation options. It is equally plausible that emergency response requirements can be met at any of the locations.

Key differences between storage concept options include:

- Options involving passive safety and security offer advantages; thus the active cooling approach in the pond concept is not ideal, whereas the other storage concepts offer passive cooling. Simple approaches with minimal handling (e.g.

vault concepts) will help minimise the risk of accidents and thus emergencies. Cask options also help reduce the risk associated with accidents by reducing the likely impact of any one event.

Similarly, the following comments reflect key differences between the KVU building concept options:

- ▲ The underground and bunker building concepts offer passive safety and thus emergency response benefits. However they would need to be carefully engineered to support monitoring and adequate emergency response plans.

Full descriptions of relevant elements of the KVU location, concept option and building option comparisons are provided under Task 3 and Task 4.

4.5 Social / Socio-economic Aspects

4.5.1 Overview of Social / Socio-economic Requirements

As highlighted in Section 4.1, the fundamental requirement from international guidance and Norwegian legislation and regulations (e.g. Norwegian Government, 2000) is the demonstration of optimisation in radioactive waste management. This means that protection of human health and the environment is the priority, balanced against impacts associated with other criteria concerning practicability and cost.

Protecting human health and the environment is also a core part of protecting the wider community. In addition a range of wider aspects are of relevance, and it is these that are discussed here. Note also that direct programme financial costs are also considered elsewhere; however, the net economic impacts on communities is considered in the following discussions.

In addition to demonstrating optimisation, and plans and programmes for storage of radioactive material will need to be subject to EIA as part of the planning and construction process. Norwegian EIA regulations (Norwegian Government, 2009) note a range of potential impacts and considerations that are relevant to local community concerns on aspects such as resources and amenity value (see Box 2).

International best practice resource such as IAEA (2002) provide further guidance on socio-economic matters that should be considered in store location and design option programmes.

Aspects of relevance for long-term storage include:

- ▲ Ensuring at least the same level of protection (safety, security) for future populations as for those that exist now.

- Minimising reliance on future generations to actively maintain the facility (burden).
- Considering the net economic benefit of the plans for local, regional and national communities (jobs, local investment etc.).
- Minimising nuisance and disturbance e.g. road transports through habitations during constructions and operations, noise, dust etc.
- Impacts on amenity e.g. local parks, areas of natural beauty, resources used for recreation, etc.
- Visual impacts.
- Perceptions of impacts by association with a radiological facility.
- Impacts on or indeed benefits to local infrastructure.
- Changes to the makeup of communities.
- Impacts on local monuments, areas, resources or buildings of special cultural or historical interest.

4.5.2 Social / Socio-economic Aspects: Commentary on Discriminating Factors between KVU Localisation and Storage Concept Options

The following discussions provides input to (and is consistent with) the options discussions on localisation (Task 4) and building and concept options (Task 3).

Localisation

In broad terms, social and socio-economic characteristics of sites with a pre-existing nuclear industry presence will differ from those with without such experience. These differences relate mainly to a different perception of the risks associated with nuclear activities that are borne of direct experience. It can also be the case that local people have benefited economically from the industry, either working directly for the facilities or though secondary effects, e.g. as a result of increased affluence in the area. However, although there is ample evidence that these broad trends exist, it is important that social and socio-economic aspects are explored directly with the local population for a particular site. As such, these issues are best addressed within subsequent siting processes for any of the generic locations.

Storage and Building Concept Options

In the most part, impacts on communities will be similar for each of the suggested approaches; they all involve a similar size facility, numbers of transports, infrastructure requirements, etc. These will be important aspects for future detailed siting and design considerations and related planning processes, but do not provide significant differentiation between options for this KVU.

However there will be some advantages in terms of storage concept options that involve passive safety/security, as this will minimise the requirement for future generations to continue to actively operate the store, thus reducing "burden". The flipside of this is that options that rely on passive safety / security may require fewer active on-site operators in the longer term; it is even possible that once waste receipts have been completed, the active on-site presence could be minimal or even zero with a reliance on passive safety and remote / occasional surveillance. In such a case, the reduced number of local jobs being provided may be considered a negative differentiator. However, in any case the number of operators will not be large.

4.5.3 Social / Socio-economic Aspects: Summary of Input to Opportunity Study

The main potential differentiator between storage and building concept options concerns the underground and bunker building options, both of which offer passive safety and thus reduce burden on future generations. However, this needs to be balanced against the potential lower long-term socio-economic benefit (passive safety may mean fewer local jobs).

Visual impact may be a considered an issue for surface facilities if within "line of sight" of local populations or amenities.

4.6 Requirements for Monitoring Plans

4.6.1 Overview

The previous sections detail a range of important considerations for the safety and security of waste and spent fuel storage. The key safety, environmental protection and security functions described need to be underpinned by monitoring demonstrating continuing safety and enabling action to be taken if any risks or issues are identified. In what follows, potentially important components of monitoring plans are highlighted, taking account of the requirements previously described. The discussion includes a note on how monitoring for stores for treated spent fuel may differ from those for unstable spent fuel, and also indicates the additional monitoring likely to be required for a disposal facility. Input resources include IAEA (2006), IAEA (2011a) and IAEA (2004), which together provide information on generic requirements in this area.

4.6.2 Requirements

Monitoring and surveillance for waste and spent fuel stores covers a range of requirements. These are highlighted and expanded upon in Table 1 below.

The table is necessarily generic and high-level. The actual monitoring regime for a store will depend on the nature of the building concept, the status of the wastes and/or spent fuel e.g. their stabilisation and conditioning status, the waste containers and so on. It is not possible to be more specific without tying in to a particular detailed design or plan. The table therefore aims to list the main monitoring approaches that may be of relevance at a level of detail appropriate to the KVU.

Note that international guidance is clear that monitoring arrangements, as for other aspects of radioactive material management, should be proportionate to the hazard posed for the material. Thus for LLW and SL-ILW, although similar categories of requirements apply, the extent of monitoring can be appropriately reduced.

4.6.3 Additional Requirements for Disposal

While storage is the key focus of the KVU there is also a requirement to identify, at a high level, potential differences for disposal. Referring to Table 1 as a baseline, Table 2 describes how monitoring requirements may change for disposal, and the types of additional requirements likely to be encountered.

Table 1: Waste / Spent Fuel Store Monitoring Requirements Overview

Target/requirement	Typical activities	Additional Notes
Monitoring of the wastes and/or spent fuel and containers to identify any changes in status and to check that any changes are within the range expected (e.g. reduction in radioactivity and heat output with time). Monitoring of the waste and/or spent fuel containers to ensure they continue to provide the shielding / containment functions they were designed for.	Container surface radiation monitoring (e.g. remote) Container surface temperature monitoring (e.g. remote) Atmospheric external radiation monitoring within plant buildings Atmospheric contaminant monitoring and analysis Within plant liquid and gas contamination monitoring and analysis Monitoring of gas/particulate filters etc Use of fixed and portable monitoring equipment Monitoring for environmental conditions (humidity, temperature, etc) Surface corrosion and salt monitoring Mechanical monitoring e.g. strain	A fundamental requirement for all stores, but the level of monitoring will be informed by the nature of the wastes and spent fuels. Unstable spent fuel will require more active monitoring than treated stable spent fuel, and more analysis, to help track its evolution and also to support characterisation for final treatment and disposal. This may not be an "order of magnitude" difference but nevertheless could be notable from a resource/cost perspective.
Surveillance of facility and monitoring equipment to ensure it continues to provide the required functions, including ensuring emergency response-relevant equipment is maintained in case of an event.	Checking and maintenance regime of alarms, response systems, automatic barriers etc Radiation monitoring of equipment	Equally necessary for all stores.
Monitoring of workers including protective equipment, clothing and the workers themselves to confirm sufficient radiological protection.	Facility entry/exit worker monitoring Portable "badge " monitoring Annual health screening and monitoring Clothing and footwear controls, monitoring during clothing washing / disposal Access controls	As for unstable untreated waste and fuel more active closer inspection may be required, monitoring and health and safety requirements may be more substantial for such materials than for stabilised wastes and spent fuel. For stabilised wastes, it may be that a substantial majority of the monitoring activities will be remote with reduced requirements to enter the storage areas.

Target/requirement	Typical activities	Additional Notes
Monitoring of physical aspects of the store building including designed physical safety barriers and security functions.	Visual inspection Integrity testing (e.g. vibration, other mechanical means) For underground systems, cavern roof inspections and monitoring, hydrological monitoring of surrounding system, surface deflection monitoring (surface of store and surface of ground above store) Shielding radiation monitoring Building vegetation checking, removal and testing	Necessary for all stores but perhaps even more important for stores with untreated wastes and fuels.
Monitoring and accountancy to confirm any discharges are within permitted levels and are as expected.	Liquid and gaseous effluent accountancy within and outside store	Equally necessary for all stores.
Environmental monitoring including air, surface waters, surface plants and animals, and subsurface resources (e.g. groundwater) to demonstrate that discharges and other impacts are not having a deleterious impact on the environment.	External radiation monitoring in surrounding environment Sampling and analysis of surface and groundwater systems Sampling and analysis of soils Sampling and analysis of atmospheric gas and dust Sample collection and testing for local plants and animals Seismic monitoring and maintenance of a seismic hazard assessment Flood risk monitoring and maintenance of a flood risk assessment if relevant Monitoring of any other identified hazards Geotechnical monitoring (water, rock stability, vibration, erosion and topographic surface deflection etc) to inform on ground stability Meteorological and climate surveys linking with the above	Equally necessary for all stores.
Security monitoring	Access controls during operations for authorised personnel Remote intruder monitoring/alarms and CCTV On-site security presence Other controls as identified (e.g. satellite/remote image monitoring of environs)	Equally necessary for all stores, although unstable fuel may be more attractive for malicious acts than stabilised fuel.

Target/requirement	Typical activities	Additional Notes
Quality assurance and analysis	Continued data storage, collation and (importantly) routine and non-routine analysis is essential in order to identify deviations and trends from expectations. The security of data and the understanding it affords (including central storage of key documents and expert staff retention and succession plans) is fundamental to effective monitoring.	Equally necessary for all stores.
Maintenance of Safety Cases (Periodic Safety Reviews)	The discipline of regular safety reviews and review and update of Safety Cases, including demonstration of compliance as well as development to take into account new data, is similarly an important component of monitoring.	Equally necessary for all stores.

Table 2: Waste / Spent Fuel Disposal Monitoring Requirements Overview, Compared to those for Storage (from Table 1; *changes and additions for disposal are in italics*)

Target/requirement	Typical activities	Commentary on disposal
Up-front characterisation (disposal)	*Geological, hydrological, hydrogeological and geochemical understanding through various forms of site investigation and time-series monitoring in advance of, during and after construction*	*To a much more limited extent this can be important for stores also, but site characterisation and monitoring is fundamental to site selection, concept choice and long-term safety for disposal systems, as the engineered and natural systems will interact for many thousands of years post-closure, and the potential evolution scenarios need to be understood from the start to demonstrate long-term safety*
Monitoring of the wastes and/or spent fuel and containers to identify any changes in status and to check that any changes are within the range expected (e.g. reduction in radioactivity and heat output with time). Monitoring of the waste and/or spent fuel containers to ensure they continue to provide the shielding / containment functions they were designed for.	Container surface radiation monitoring (e.g. remote) Container surface temperature monitoring (e.g. remote) Atmospheric external radiation monitoring within plant buildings Atmospheric contaminant monitoring and analysis Within plant liquid and gas contamination monitoring and analysis Monitoring of gas/particulate filters etc Use of fixed and portable monitoring equipment Monitoring for environmental conditions (humidity, temperature, etc) Surface corrosion and salt monitoring Mechanical monitoring e.g. strain	*Required during operations. NB all wastes and spent fuels will have been stabilised.*
Surveillance of facility and monitoring equipment to ensure it continues to provide the required functions including ensuring emergency response-relevant equipment is maintained in case of an event.	Checking and maintenance regime of alarms, response systems, automatic barriers etc Radiation monitoring of equipment	*Required during operations.*
Monitoring of workers including	Facility entry/exist monitoring	*Required during operations.*

Target/requirement	Typical activities	Commentary on disposal
protective equipment, clothing and the workers themselves to confirm sufficient radiological protection.	Portable "badge "monitoring Annual health screening and monitoring Clothing and footwear controls, monitoring during clothing washing / disposal Access controls	
Monitoring of physical aspects of the store building including designed physical safety barriers and security functions.	Visual inspection Integrity testing (e.g. vibration, other mechanical means) For underground systems, cavern roof inspections and monitoring, hydrological monitoring of surrounding system, surface deflection monitoring (surface of store and surface of ground above store) Shielding radiation monitoring Building vegetation checking, removal and testing	*Required during operations.* *After operations, there is typically a 100 – 300 year "institutional control" period where the system is "closed" and where only passive external monitoring systems remain. Continuing (external) physical aspect monitoring is likely to continue during this time.* *It is particularly important that data informing concept evolution and "safety function" provision of the various barriers is built up during the operational period to inform upon the likely long-term evolution of the system after closure and cessation of institutional control.*
Monitoring and accountancy to confirm any discharges are within permitted levels and are as expected.	Liquid and gaseous effluent accountancy within and outside store	*Required during operations – with additional requirements during operations, to build confidence in performance after operations. Understanding the evolution of the system and its effluents will be important to predicting long-term performance after physical closure and subsequently the end of institutional control.*
Environmental monitoring including air, surface waters, surface plants and animals, and subsurface resources (e.g. groundwater) to demonstrate that discharges and other impacts are not having a deleterious impact on the	External radiation monitoring in surrounding environment Sampling and analysis of surface and groundwater systems Sampling and analysis of soils Sampling and analysis of atmospheric gas and dust Sample collection and testing for local plants and animals	*As for discharges above – required for all stores with additional need to support long-term perspectives. These long-term perspectives include the additional characterisation and monitoring necessary to, for example, understand potential contaminant transport pathways in the environment in the very long term once the closed facility has degraded and wastes are able to*

Target/requirement	Typical activities	Commentary on disposal
environment.	Seismic monitoring and maintenance of a seismic hazard assessment Flood risk monitoring and maintenance of a flood risk assessment if relevant Monitoring of any other identified hazards Geotechnical monitoring (water, rock stability, vibration, erosion and topographic surface deflection etc) to inform on ground stability Meteorological and climate surveys linking with the above	*release some contaminants to groundwater.*
Security monitoring	Access controls during operations for authorised personnel Remote intruder monitoring/alarms and CCTV On-site security presence Other controls as identified (e.g. satellite/remote image monitoring of environs)	*Required during operations, and to a more limited extent, during the 100-300 year period of institutional control.*
Quality assurance and analysis	Continued data storage, collation and (importantly) routine and non-routine analysis is essential in order to identify deviations and trends from expectations. The security of data and the understanding it affords (including central storage of key documents and expert staff retention and succession plans) is fundamental to effective monitoring.	*Required during operations.*
Maintenance of Safety Cases (Periodic Safety Reviews)	The discipline of regular safety reviews and review and update of Safety Cases, including demonstration of compliance as well as development to take into account new data, is similarly an important component of monitoring.	*Required during operations.*

References

Collier, D., and Metcalfe, R., 2014. Concept selection assessment (KVU) for an intermediate store for spent nuclear fuel and other long-lived radioactive waste in Norway: Notes of a Stakeholder Meeting concerning Security and Planning Emergency Responses. QRS-1669A-TN14. /Dxxx/

IAEA, 2002. Socio-economic and other non-radiological impacts of the near surface disposal of radioactive waste. IAEA-TECDOC-1308. /Dxxx/

IAEA, 2004. Surveillance and monitoring of near surface disposal facilities for radioactive waste. Safety Reports Series No. 35.

IAEA, 2006. Storage of radioactive waste. Safety Guide WS-G-6.1. /D191/

IAEA, 2009. Borehole disposal facilities for radioactive waste: Safety Guide. IAEA Safety Standards Series SSG-1 /Dxxx/

IAEA, 2011a. Storage of spent nuclear fuel. Specific Safety Guide SSG-15. /D259/

IAEA, 2011b. Nuclear security recommendations on physical protection of nuclear material and nuclear facilities (INFCIRC/225/Revision 5). IAEA Nuclear Security Series No. 13, January 2011. /Dxxx/

IAEA, 2013. Objective and essential elements of a state's nuclear security regime. Nuclear security fundamentals. IAEA Nuclear Security Series No. 20, February 2013. /Dxxx/

Low-level Waste Repository Ltd and the Nuclear Decommissioning Authority, 2011. UK management of solid low level radioactive waste from the nuclear industry: LLW Management Plan. http://llwrsite.com/wp-content/uploads/2013/04/UK-Nuclear-Industry-LLW-Management-Plan.pdf /Dxxx/

Metcalfe, R, Paulley, A., and Penfold, J., 2014. KVU - Handling of Norwegian spent fuel and other radioactive waste: Task 4: Safety and security and emergency preparedness: localisation aspects. Quintessa report QRS-1669A-1.

Norwegian Government, 2000. Act and regulations on radiation protection and use of radiation. /Dxxx/

Norwegian Government, 2005. Regulations on environmental impact assessment. /Dxxx/

Paulley, A., 2014. (UK) National Strategic BAT for organic low level radioactive waste: Final BAT Report. Jacobs and Quintessa report for the Low-level Waste Repository Ltd, UK, Report number 60X50008_01. http://llwrsite.com/wp-content/uploads/2013/04/60X50008_Organic_LLW_National_BAT_Report_Final_Issue_12022014AP.pdf