LLW Repository Ltd

National Waste Programme

Desktop Review:

On-Site Decay Storage Principles

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A company owned by UK Nuclear Waste Management Ltd

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Glossary

ALARP	As Low As Reasonable Practicable
BAT	Best Available Technique
CfA	Conditions for Acceptance
EA	Environment Agency
EPR2016	Environmental Permitting Regulations 2010
GDF	Geological Disposal Facility
HAW	Higher Activity Waste
IAEA	International Atomic Energy Agency
ILW	Intermediate Level Waste
LLW	Low Level Waste
LLWR	Low Level Waste Repository
MOD	Ministry of Defence
NDA	Nuclear Decommissioning Authority
NRW	Natural Resources Wales
NWP	National Waste Programme
ONR	Office of Nuclear Regulation
RSA93	Radioactive Substance Act 1993
RWM	Radioactive Waste Management
SEPA	Scottish Environmental protection Agency
SHORT-LIVED ILW	ILW containing short-lived radionuclides
TRL	Technology Readiness Level
WAC	Waste Acceptance Criteria

Review Paper Structure

1. Introduction

The National Waste Programme (NWP) is delivering a project to develop on-site decay storage principles. The output of this project will be a set of practical principles to help waste producers in their decision-making around the suitability of implementing decay storage on their sites for relevant Intermediate Level Waste (ILW) (including Low Level Waste (LLW)/ILW 'boundary waste')[1]. It will provide information on the opportunities and associated barriers and challenges that need to be addressed. The project comprises the following stages:

- A desktop review of UK policy, regulation and guidance in relation to the storage of radioactive waste and decay storage (this document); drawing together preliminary thinking on the factors that may influence the decision by waste producers to adopt on-site decay storage for the management of specific wastes. It reviews some examples of UK and international storage in the context of these principles. The review report provides background information to support the workshop.
- A stakeholder workshop (involving waste producers, regulators, Radioactive Waste Management Limited (RWM) and the Nuclear Decommissioning Authority (NDA)) to explore the site specific issues and practicalities around decay storage, and to identify case studies to include in the final report.
- The final report collating information gathered and presenting a set of practical principles for implementing on-site decay storage by waste producers.

The project scope includes:

- Decay storage, where decay storage is to access a predetermined waste route.
- Decay storage of ILW for disposal or treatment as LLW.
- On-site[2] decay storage at waste producer sites, where the waste is either:
  - o stored in-situ and retrieved at a later date
  - o retrieved and containerised (but not necessarily conditioned) prior to storage.

The project scope excludes:

- Consideration of any future national centralised storage site.
- Decay storage on the Low Level Waste Repository Ltd (LLWR) site and in the Dounreay Site Restoration Ltd LLW facility (as authorised).
- Decay storage on a supply chain site.
- Decay storage (ex-situ or in-situ [1]), as a precursor to disposal to a Geological Disposal Facility (GDF) [3] or near-site near surface disposal facility (Scotland)[4].

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[1] The principles may also prove useful when using decay storage as a management option for other radioactive wastes to facilitate application of the Waste Hierarchy across the radiological spectrum.

[2] It is recognised that waste producers with multiple sites may choose to centralise, or regionalise, decay storage facilities.

- as a precursor to in-situ disposal - considerations and requirements for this are described in the environment agencies' 'Guidance on Requirements for Release of Radioactive Substances from Regulation (GRR), February 2016' (Consultation Document) [8].

2. Background

> Decay storage is the process of using time as a treatment to allow reactivity to subside, or radioactive decay of short lived radionuclides to reduce to specific activity levels, either in-situ or containerised [2].
>
> In the context of this project, it is defined as a conscious and deliberate waste management action to access a predetermined waste route.

On-site decay storage is considered to be a potentially useful waste management technique for ILW, including ILW dominated by short-lived radionuclides[5].

Decay storage of ILW with suitable radiological, chemical and physical properties, could enable the waste to meet the necessary WAC for appropriate treatment or disposal routes. This could include both existing routes or technological solutions close to technology readiness, where demonstrably BAT and optimised.

Decay storage, therefore, provides the opportunity to consider as BAT (Best Available Technique) a wider range of waste management routes[6] than geological disposal for ILW (or near-site near-surface disposal in Scotland). It has the potential to support improved application of the waste hierarchy [3] and the diversion of ILW away from the

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[3] An example of this is the Magnox SAFESTORE concept involving in-situ decay storage of wastes prior to conditioning and packaging. In the context of Magnox strategy, the SAFESTORE concept would be applied to the de-fuelled reactor cores, which are placed in a passive safe state prior to dismantling and decommissioning. The SAFESTORE concept was implemented in 2010 for two reactors at the Berkeley site, such that at the time of final site clearance (approximately 60-70 years), the Co60 dose associated with activated reactor components, would be significantly reduced [1].

[4] For the remainder of the document, where comments relating to GDF disposal are relevant to Scotland this should be taken as applying to a near-site near-surface disposal facility in Scotland.

[5] Short-lived radionuclides could be considered as those typically with half-lives of less than 30 years, which include Cs137 (30 year half-life), Sr90 (29.1 year half-life), H3 (12.3 year half-life) and Co60 (5.3 year half-life). These radionuclides would undergo significant radioactive decay within the next 300 years, such that waste containing these radionuclides could potentially be managed at a lower radioactive waste category.

[6] Potential routes currently include: surface disposal (e.g. the Low Level Waste Repository in England, or the near-surface disposal facility in Scotland), or management via alternative existing treatment routes (Metallic, Combustible and VLLW (Very Low Level Waste) disposal).

GDF. For waste requiring little or no pre-treatment before being decay stored, there is also the potential to reduce exposure of waste operatives to the radiological and non-radiological hazards associated with treating and processing ILW for interim storage prior to disposal to a GDF; thereby supporting the principle of ALARP (As Low As Reasonable Practicable).

NDA strategy [4] is committed to consider decay storage of ILW, such that the updated 2017 Industry Guidance for the interim storage of higher activity waste packages recognises the use of decay storage, and includes a decay storage management approach [3]. RWM also recognises decay storage as a credible approach for long-term management of ILW [1].

A recent National Waste Programme study [5] identified that an estimated 20% of the total ILW in the UK Radioactive Waste Inventory may comprise Short-lived ILW[7], which equated to a total volume of 51,500 m^3. Of this volume:

- ~1,900 m^3 was identified as an opportunity for disposal through alternative routes other than the GDF, such as the LLW Repository. However, it was acknowledged that some operational changes would be required to accommodate a small volume of wastes falling into this category (e.g. changing safety cases, or modifying infrastructure).
- ~39,300 m^3 was identified as having uncertainties that may prevent disposal to facilities other than the GDF e.g. inventory uncertainty and uncertainties in relation to meeting Waste Acceptance Criteria (WAC) of alternative disposal facilities.
- A further ~10,400 m^3 was identified as having more significant challenges, including wastes for which no characterisation has been undertaken but where they were deemed to have very low probability of suitability for management as LLW. An additional barrier to alternative disposal routes is that these wastes are scheduled to be packaged by 2021, specifically for GDF disposal.

These figures illustrate the potential size of the opportunity to divert waste from GDF disposal and improve application of the waste hierarchy (consistent with NDA strategy [4] and regulatory guidance [6]); they also highlight significant areas of uncertainty and additional work required to enable or rule out alternative management.

Despite the supportive policy environment, the potential opportunities that may be realised and an increasing focus by site operators and regulators on a risk-based approach to decision making on waste management, on-site decay storage of ILW has not been widely employed. Two underlying and connected drivers for this may be: the

[7] Short-lived ILW was defined in the study as ILW whose disposal at arising would be compliant with the radiological requirements of the current environmental safety case (ESC) of the LLWR in Cumbria [5].

predominant waste management approach and supporting management processes are organised around radiological category rather than risk, resulting in opportunities for alternate management not being fully explored; and, whilst decay storage is a well understood technique, it is not an option readily consider as a familiar and relevant waste management tool for ILW.

In addition, the extended period of time that waste producing sites would be required to store waste and the need for appropriate storage facilities may be a barrier to its adoption; presenting a resource/cost burden around the secure provision and maintenance of suitable storage facilities, where these do not already exist. The extended period of time may also conflict with some site end-state schedules and, if very long, could pass the waste management burden to future generations.

Despite these potential issues, useful examples of decay storage being successfully employed for the management of ILW do exist [3] (see Section 7):

- Rosyth Dockyard (Ministry of Defence – MoD) is decay storing, ion exchange resins that contain H3 and Co60. These resins are expected to undergo significant decay and become LLW within the next 6 years. Following decay storage, the resins will then undergo thermal treatment to destroy the organic complexing agents followed by conditioning of the residue for disposal at the LLW Repository Ltd [7].
- Chapelcross (Magnox Ltd) is decay storing tritiated ILW in sealed containers (500 litre drums and Temporary Storage Vessel overpacks) for 150 years until the waste can be disposed of as LLW.
- Untreated tritiated steel at Dounreay (Dounreay Sites Restoration Ltd (DSRL)) is being decay stored in Half-Height ISO containers. The waste will be stored for around 40 years until the waste can be disposed of as LLW.

3. Objectives of Decay Storage

Potential Objectives of Decay Storage may include:

- Optimising application of the waste hierarchy – decay storage may enable waste to be managed at the lowest possible category, diverting ILW away from the GDF and potentially facilitating treatment, free release, recycling, or re-use.
- Providing an optimised (i.e. BAT and ALARP) waste management approach that may enable:
  - a broader range of treatment/disposal routes to be accessed following decay storage
  - a reduction in operator exposure – this may be particularly true for wastes that would not be pre-treated prior to packaging for decay storage; and
  - the activity associated with any secondary waste arisings from treatment to be minimised until the waste has decayed to LLW [2]. Such secondary arisings could include processing equipment required to size reduce, package or condition ILW waste.
- Avoiding foreclosing management options – storing waste in a packaged and conditioned form for GDF disposal may foreclose LLW disposal and treatment options that are close to technology readiness.
- Reducing costs – where ILW can be reclassified in a relatively short timeframe. The cost of decay storage may be lower than the costs associated with interim storing ILW that is waiting for a GDF to become available.

Waste producers may have different objectives and drivers for considering decay storage depending on the nature of the wastes and the level of maturity of existing waste management strategies and infrastructure; these will be explored at the stakeholder workshop.

4. Policy, Regulation & Guidance for Radioactive Waste Storage

4.1. International Guidance

The International Atomic Energy Agency (IAEA) has established a number of safety standards with the aim of protecting health and the environment, whilst minimising danger to life and property. These standards are used by the IAEA in its own operations and have been adopted by many member States for use in national regulations.

Safety standard WS-G-6.1 [8] relates to the storage of radioactive waste and provides recommendations to regulatory bodies and operators of nuclear sites for meeting the safety requirements associated with the storage of radioactive material in general (not specifically decay storage, although it is acknowledged within the standard). The safety guide covers a number of key areas relating to radioactive waste storage including: protection of human health and the environment; roles and responsibilities (government, the regulatory bodies, and the operators); common safety considerations; design and operation of small storage facilities for radioactive waste; and the design and operation of large storage facilities for radioactive waste.

According to the safety standard, passive safety is the common safety consideration for all radioactive storage facilities, including higher activity radioactive waste.

Passive Safety

The overarching recommendations for achieving this include [8]:

- the radioactive material should be immobile
- the waste form and its container should be physically and chemically stable
- energy should be removed from the waste form
- a multi-barrier approach should be adopted in ensuring containment
- the waste form and its container should be resistant to degradation
- the waste storage environment should optimise the lifetime of the waste package
- the need for active safety systems to ensure safety should be minimised
- the need for monitoring and maintenance to ensure safety should be minimised
- the need for human intervention to ensure safety should be minimised
- the waste storage building should be resistant to foreseeable hazards
- access to the waste storage building should be provided for response to incidents
- there should be no need for prompt corrective action in the event of an incident
- the waste packages should be able to be inspected
- the waste packages should be retrievable for inspection or reworking
- the lifetime of the waste storage building should be appropriate for the storage period prior to disposal of the waste
- the waste storage facility should enable the retrieval of waste
- the waste package should be acceptable for final disposal of the waste.

4.2. UK Policy

The principles of the IAEA guidance [8] have been incorporated into UK policy on the storage of radioactive waste. Separate policies relating to the management of radioactive waste in England, Wales, Scotland and Northern Ireland have been published. The following sub-sections provide a short summary of each policy in relation to radioactive waste storage.

4.2.1. England

The policy for England is outlined in the 2014 White Paper [9] and states that higher activity waste will be managed in the long-term through geological disposal, with safe and secure interim storage. The English policy defines storage as:

'*The placement of waste in a suitable facility with the intent to retrieve it at a later date'*

In this respect, the storage of waste is essential in providing a safe temporary environment prior to disposal. Therefore, the facilities intended for storing higher activity wastes should be robust, engineered facilities that are capable of providing safe and secure protection for waste packages. Moreover, they should prevent hazardous releases to the outside environment via a number of engineered barriers and environmental controls. Storage facilities should be designed to withstand foreseeable incidents such as earthquakes and severe weather, and they perform a security role by being a barrier to unauthorised intrusion [9].

4.2.2. Scotland

The policy for Scotland [10] is that the long-term management of higher activity radioactive waste should be in 'near surface, near site' storage and/ or disposal facilities where the waste can be monitored, retrieved (if required) and the need for transportation over long distances is minimised.

The Scottish policy is based on the principles of the Waste Hierarchy (reducing the amount of higher activity waste requiring disposal) and proximity (storing and disposing the waste at locations as near to the originating sites as practicable). In-line with these principles there are three primary options for the long-term management of the waste: treatment; storage; disposal.

The Scottish policy defines storage as: '…. *Placing the waste in a suitable facility with the intent to retrieve it at a later time*……'

Requirements within the policy include the presumption that a storage facility will be as near to the surface as practicable taking account of all factors. Moreover, the policy clearly stipulates that the waste should be retrievable and monitored throughout the storage period.

4.2.3. Wales

Since 2008 the Welsh Government policy is neither to support nor to oppose the UK government policy of geological disposal for Higher Activity Waste (HAW) and spent fuel classed as waste. Nor does the Welsh Government currently support any other disposal option for these wastes [6]. Following a consultation [11], the Welsh Government is currently reviewing the responses received and will publish its findings and clarify its policy decision in the near future.

4.2.4. Northern Ireland

The 2014 White Paper [9], which was discussed in Section 4.2.1, was issued jointly by the UK Government and the Northern Ireland Executive. Northern Ireland continues to support the implementation of geological disposal for the UK's higher activity radioactive waste, recognising that it is in the best interests of Northern Ireland that these wastes are managed in the safest and most secure manner. The Northern Ireland Executive has responsibility for ensuring that any proposed GDF will not have an adverse impact upon the environment, health or safety of Northern Ireland [9].

4.3. UK Regulatory Framework

The management of radioactive waste is regulated by the Office of Nuclear Regulation (ONR), Environment Agency (EA), Scottish Environmental protection Agency (SEPA) and Natural Resources Wales (NRW). The roles and responsibilities of each regulator are briefly described below [12]:

ONR

The ONR is responsible for securing effective control of health, safety, radioactive waste management and security at nuclear sites to protect the public and workers from radiation. The management and storage of radioactive waste on nuclear sites is regulated via the nuclear site license granted under the Nuclear Installations Act 1965. There are 36 licence conditions attached to all nuclear licences. The licence conditions of particular relevance to radioactive waste storage are [12]:

- **Licence Condition 4** requires that no nuclear matter is stored on the site except in accordance with adequate arrangements made by the licensee for this purpose.
- **Licence Condition 25** requires that adequate records are kept of the amount and location of radioactive waste used, stored or accumulated on site at any time.
- **Licence Condition 34** requires the licensee to ensure, so far as is reasonably practicable, that radioactive material and radioactive waste on the site is at all times adequately controlled or contained so that it cannot leak or otherwise escape from such control or containment.

The above licence conditions are relevant to storage, however it is worth mentioning **Licence Condition 32** (accumulation of radioactive waste), which requires the licensee to make and implement adequate arrangements for minimising, so far as is reasonably practicable, the rate of production and total quantity of radioactive waste accumulated on the site at any time, and for recording the waste so accumulated. This would imply that opting to store wastes for extended periods of time may contravene this licence condition. However, this condition also states that where radioactive waste is accumulated or stored, it complies with such limitations as to quantity, type and form as may be specified by ONR. Moreover, the licensee shall, if so specified by ONR, not accumulate radioactive waste except in a place and in a manner approved by ONR.

The implementation of decay storage would therefore be in accordance with Licence Condition 32 providing the storage complies with ONR limitations and is stored in suitable manner. The ONR supports the use of decay storage (which is evidenced by the joint guidance, which is discussed in Section 6) providing the approach is appropriately justified and supported by appropriate safety cases.

Environment Agencies
There are a number of environment agencies covering England (EA), Scotland (SEPA) and Wales (NRW). These agencies are responsible for regulating any disposal, discharge or off-site transfer of radioactive waste [12]. The environment agencies advise the ONR on the long-term protection of the public and the environment. Within their remit, the agencies provide advice on the disposability of conditioned waste in the long term, and ensuring waste is managed in a sustainable way, taking into account long-term environmental considerations.

In England and Wales, the Environmental Permitting Regulations 2016 (EPR2016)[8] is the legislation which the EA and NRW work to in regulating the disposal of radioactive waste. In Scotland, SEPA regulates under the Radioactive Substance Act 1993 (RSA93). The requirements of the EPR2016 and RSA93 are similar [12].

Joint Guidance
The ONR and environment agencies (EA, SEPA and NRW) work together to optimise the arrangements for the management of radioactive wastes on nuclear licensed sites. Waste packages should be suitable for disposal following the storage period; hence a joint regulatory approach ensures that the long-term disposability of conditioned waste meets the requirements of the appropriate environment agency. The aim of a joint approach is to minimise the requirement to re-work the package for future disposal. This joint regulatory position is outlined in Reference [13]. Two joint guidance documents have been published:

- Basic Principles of Radioactive Waste Management [12].
- The Management of Higher Activity Radioactive Waste on Nuclear Licenced Site [6].

The latter of these documents provides guidance on the storage of radioactive materials and is discussed in Section 6.

[8] Previously EPR2010, which was updated in December 2015 following a 10 week consultation launched by Defra and the Welsh Government. Following the consultation period, the EPR2016 came into force on 1st January 2017.

5. Decision Factors in Decay Storage Decision-Making

The objective of this section is to identify factors that may need to be considered when deciding on the applicability of on-site decay storage. Consideration of these factors may dictate the suitability of the approach. Some considerations, or decision factors, are noted below, although it is recognised that they may vary from one waste producer to another:

- Suitability of the waste for on-site decay storage.
- Timescales required for decay storage.
- Suitability for the future management route.
- Infrastructure and resources required.
- Challenges and uncertainties.

5.1. Suitability of the Waste for On-Site Decay Storage

Characterisation of the waste to gain knowledge of the radionuclide inventory is required to facilitate their subsequent management [6], and confirm the suitability of the waste for decay storage. Characterisation of the waste may show that the stream contains wastes bearing both short-lived and long-lived radionuclides, such that segregation of wastes, if possible, may be required prior to implementing decay storage [3].

Furthermore, characterisation of the waste and an understanding of the physical, chemical and radiological characteristics may also be required to demonstrate that there would be benefits in not conditioning the waste as soon as reasonably practicable. This would support the case to decay the waste and is consistent with the UK nuclear regulators' joint guidance document [6].

Characterisation would also be required to support the longer-term management following the decay storage period. For example, characterisation data may be required to demonstrate that the decayed waste would meet the requirements for future consignment to disposal or treatment / processing facilities. The decision not to decay store the waste may be made if characterisation shows that that the waste is unlikely to meet the requirements of the intended disposal or treatment / processing facility. This is discussed again Section 5.5.

Thus, the key questions, or considerations, with respect to the suitability of wastes for decay storage may include:

- Has the waste (primary waste & any resulting secondary waste) been characterised and are the chemical, physical and radiological characteristics understood?
- Do the characteristics of the waste favour conditioning as soon as practicable?
- Does, or can, the waste need to be segregated to separate the short-lived and long-lived radionuclides?
- Through analysis of the characterisation data (both radiological and non-radiological), can it be demonstrated that the wastes would be suitable for future treatment/disposal following decay storage?
- Will any planned conditioning or packaging prevent or make problematic acceptance at the treatment and/or disposal facility or prevent transportation?

5.2. Timescales Required for Decay Storage

The timescales required to store the waste until its activity level reaches that of LLW would be dependent on the constituent radionuclides. For example, for some waste streams (e.g. the MOD resins held at Rosyth) benefit could potentially be gained, through reclassification of ILW as LLW, following decay storage for as little as a few years. In others cases, many decades or more of storage may be needed to achieve radioactive decay required to categorise as LLW [2].

The end state of the waste producing site may dictate whether decay storage is a feasible management option for ILW. If the time required to decay store waste to LLW is only a few years, then decay storage may be a viable option. In contrast, if 300 years is required, then the decay period may extend beyond planned site end states making decay storage a less attractive option. A long period of storage may make this approach financially non-viable.

The Scottish policy on radioactive waste management (see Section 4.2.2) calls for long-term management in near surface facilities and considers that up to 300 years is an acceptable period for institutional control. In this respect, the decay storage of waste in surface facilities for up to 300 years would be consistent with Scottish policy, but may not be consistent with English and Welsh policy.

Thus, the key questions or considerations with respect to decay storage timescales may include:

- What timescales would be required for the waste to decay to LLW?
- How does this compare with timescales and priorities for GDF disposal and how does it fit with the principle of Early Solutions?
- Do the timescales for decay storage align with planned site end-state schedule (where the decay store is located) and relevant UK policy?

5.3. Suitability for the Future Management Route

Early engagement with the disposal facilities, or providers of treatment / processing that may receive the waste following the decay storage period would be required. Post decay storage options currently include:

- recycling
- direct LLW / VLLW disposal
- supercompaction (prior to disposal)
- metallic waste treatment (size reduction, shot-blasting, and melting)
- incineration.

Routes may be applicable to both the primary and secondary wastes generated following the decay storage period.

The aim of the engagement would be to ensure that the wastes (including any packaging or conditioning) would be acceptable following the decay storage period and meet the necessary Conditions for Acceptance (CfA) and WAC for the candidate disposal or treatment / processing facility. Likewise, if the longer-term management route following the period of decay storage involves transporting the waste to an off-site location, then the transport requirements should be considered. This is discussed again in Section 5.5.

5.4. Infrastructure and Resources Required

Some degree of waste pre-treatment may be required prior to decay storage e.g. segregation of waste items having short-lived radionuclide constituents [3]. Such operations would clearly require appropriate facilities and resources.

A key component to facilitate decay storage would be the selection of an appropriate container. The packaging would need to be suitable to fulfil the principles of radioactive waste storage (Section 6), which should provide a physical barrier to enable effective containment and prevent leakage of radioactive material. The container should also be resistant to corrosion, or degradation, such that it performs its containment function during the entire storage duration, and can be retrieved at the end of the storage period [6]. Consideration should be given to the type of container and whether the waste should be packaged in accordance with future transport requirements, or to satisfy the requirements of the future treatment/processing facilities where the waste would ultimately be consigned. This may mean that the waste is packaged as LLW, despite it being ILW at the time it enters decay storage [3].

Another key aspect for on-site decay storage would be the provision of facilities that are suitable for storing radioactive wastes for the entire period. A number of key principles in relation to the storage of radioactive waste are presented in Section 6 (Table 2). These principles include the provision of a purpose built facility that has appropriate arrangements for security, safety and long-term management (including the periodic inspection and monitoring of waste packages). The implementation of these principles would mean that resources are required throughout the storage period.

The provision of a suitable facility may not be economically viable, unless it already exists on the waste producing site, and would be suitable for the extended period. If such facilities are already in existence, then decay storage may offer environmental benefits [3]. The availability and suitability of existing facilities may therefore be a key consideration.

When considering the suitability of storage facilities, the waste producer would also need to consider whether changes to existing safety cases, permits, or licences are required from the relevant regulatory body.

Thus, key questions or considerations with respect to infrastructure and resources include:

- Are pre-treatment facilities available?
- Can a container be identified that is suitable for containing the ILW waste, storing for the required decay storage timescales and compatible with future? transport/management route requirements?

- If a suitable container cannot be identified, would facilities be available during or after the decay storage period to re-pack, or overpack the waste to make it compliant with transport and/or treatment/disposal WACs?
- Is a storage facility (that meets all the requirements for decay storage) already available or planned? Or would a significant investment be required to construct a suitable facility?
- Would resources be available for the duration of the decay storage period?
- Would changes to existing safety cases, permits or licence conditions need to be made?

5.5. Challenges and Uncertainties

After decay storage, the wastes may require treatment and containerisation for final disposal, if suitable treatment and containerisation has not already been undertaken prior to decay storage. Key constraints at this stage will be to meet treatment (where applicable) and then disposal facility WAC. Compliance with transportation criteria will also be required. Wastes in the scope of this study will typically be disposed to the LLWR, the Dounreay LLW Facilities or another surface disposal facility. Similar considerations apply for waste being diverted for treatment or VLLW disposal.

Sufficient non-radiological and radiological characterisation and monitoring, and associated records keeping, will be essential in ensuring decay storage opportunities can be realised. To demonstrate wastes meet treatment and/or disposal facility WAC it will be important that the original radioactivity content is understood and that subsequent monitoring data show that radioactivity levels have decayed as expected. The physical condition of the wastes and other aspects will also need to be monitored to ensure the decay stored wastes will meet transport requirements and related aspects of treatment and disposal facility WAC. However, many waste streams are yet to be retrieved, so have limited characterisation data, or information on their physical, chemical and radiological characteristics. Such uncertainties in waste stream inventories may cast doubt on the suitability of the wastes for future treatment and disposal. Un-retrieved waste with limited characterisation data may, therefore, represent both a challenge and uncertainty with respect to decay storage.

At present, wastes are typically disposed to LLW facilities if it can be shown they meet the UK's definition of LLW, as well as other WAC. However, the permits for sites such as LLW Repository Ltd increasingly define overall radiological capacities rather than waste categorisation based limits. National strategy, policy and regulatory guidance documents also favour a risk-based approach, rather than conformance to historic waste categories[9]. Therefore, determination of the precise point at which a waste becomes suitable for acceptance at a predetermined facility needs to reflect any changing WAC

[9] Note that decay storage of ILW is not discussed in detail in UK national strategy and regulatory guidance documents, other than to recognise there are potential opportunities that should be appropriately considered within risk-informed decision processes.

requirements, handling requirements and capacity constraints rather than historic waste categories.

Given current disposal concepts, for example, it will be important to show that wastes will not require shielding after decay storage and that handling doses will be acceptable. Changes to the disposal facility concept would be needed if wastes needing shielding or with other handling restrictions are to be disposed. See [14] and [5].

More generally, it will be key that waste producers undertaking decay storage ensure that data is available (including addressing any waste treatment) to provide confidence that waste categorisation or risk-based criteria and other WAC can be met. It will be necessary to have such confidence in advance of deciding to undertake decay storage, and subsequent monitoring will need to corroborate assumptions made. It will therefore be important to plan for obtaining that data and then managing the information over time when deciding whether to decay store at the waste producer site.

It is possible that additional treatment options may become available during the period of decay storage. Nonetheless, it will be important to identify a clear waste management route as the basis for any decision to decay store; but it may be relevant to consider flexibility to address potential future treatment opportunities as part of any assessment of management options in the decision process. If flexibility is considered important, it will then be necessary to ensure data collection and monitoring approaches take this aspect into account. Alternatively, a key risk concerns the potential for future unavailability of a disposal or treatment route, e.g. if facilities close or no longer accept radiological wastes. Decision processes will have to show that the proposed approaches are suitably robust to this possibility.

A further risk is that treatment or disposal facility WAC, or related regulatory requirements, could change in the period during which wastes are decay stored. Hence, there would be greater confidence on being able to implement the identified management route for shorter periods of decay storage (e.g. 6-10 years), compared to medium periods (e.g. 40-70 years) or longer periods in excess of 100 years.. It will be important to understand any related risks and to liaise appropriately with stakeholders during the decision process to ensure there is appropriate confidence in later stages of the waste management cycle. An example of a potential area of concern is if waste inventories are very close to key acceptance criteria, capacity limits or specific limits (such as radionuclide content) that could change, e.g. as a result of future waste facility regulatory submissions, or changes to transport regulations, etc. If wastes, once decay stored, are projected to easily meet such criteria under current requirements then there will be higher levels of confidence that the wastes will be manageable via the identified route even in the event of change to requirements.

Thus, key questions or considerations with respect to challenges and uncertainties include:

- Is there an alternative management route if the wastes cannot meet the CfA/WAC for off-site transport and treatment/disposal at the end of the decay storage period?
- Can further monitoring and inspection of the wastes be undertaken throughout the decay storage period?
- Can the decay stored waste be adequately handled after decay storage period to enable transport and future treatment/disposal?
- What is the likelihood of the wastes (and their planned packaging or conditioning) failing to meet either the CfA/WAC of a disposal/treatment route, or future regulatory requirements? The likelihood may be based on the known characteristics of the waste along with the decay storage time period.
- Is additional treatment or characterisation likely to be required?
- How will new treatment or disposal opportunities be developed or tracked.

5.6. Decay Storage Opportunities, Challenges and Uncertainties and the Waste Management Lifecycle

This section draws together the decay storage opportunities, challenges and uncertainties; identified through discussing the decision factors in earlier sections of the report. These have been assigned, provisionally, against the stages of waste management lifecycle where they are judged to be potentially relevant. It is recognised that there may be further opportunities, challenges and uncertainties specific to waste producers that remain to be incorporated.

It is recognised that wastes which may be considered for decay storage may be at different stages along the lifecycle of waste management; for example, some waste may yet to be retrieved, whilst other wastes may already be characterised and contained. Two types of opportunity are listed in Table 1; at the start of the waste management lifecycle, the opportunities relate to facilitating decay storage e.g. if waste it yet to be retrieved, then it could be done to allow short-lived and long-lived ILW to be segregated. However, at the latter end of the lifecycle, the opportunities relate to the benefits realised from implementing the approach e.g. management of waste at a lower category, or diversion of waste from the GDF.

A series of arrows indicating the different ‘entry points’ at which decay storage may be considered within the waste management lifecycle are presented in Table 1; these entry points are:

- entry point 1: Prior to waste retrieval
- entry point 2: Prior to pre-treatment
- entry point 3: Between packaging and storage
- entry point 4: Following storage.

Different considerations, or key questions, may need to be resolved at each of these entry points to understand whether on-site decay storage is a viable management route for a given waste stream.

Table 1: Waste management lifecycle and potential decay storage opportunities, challenges and uncertainties

1 2 3 4

Where practicable, good practice is for planning and early characterisation to be carried out in advance of waste retrieval to inform strategic decision-making and influence decommissioning methodology; it should consider all the stages in the waste lifecycle and the factors highlighted in the table below.

	Waste Retrieval	Characterisation	Pre-Treatment	Packaging	Decay Store	Characterisation	Consignment (Treatment or Disposal)
Opportunities to facilitate decay storage & for adopting decay storage	+ Retrieve in a manner to support proposed treatment/disposal/transport route. + Segregation of short-lived and long-lived ILW could be undertaken at retrieval, so avoids double handling. + Waste could be contained in appropriate container immediately upon retrieval, so avoids double handling. + Prove planned waste conditioning and packaging suitable for proposed treatment/disposal/transport options. + Waste could be characterised during retrieval, ensuring that the correct characterisation data is acquired to support decay storage.	+ Prove suitability of waste for decay storage. + Prove suitability of waste for proposed onward treatment / disposal/handling/ transport options. + Identify potential benefits of not conditioning the waste immediately. + Collect data to demonstrate suitability of waste for future transport/treatment, or disposal.	+ Waste could be processed in a manner that meets the principles of radioactive waste storage. + Waste could be processed in a manner that is acceptable for proposed future disposal / treatment / handling / transport options. + To address concerns for passive safety.	+ May be possible to avoid double handling by packaging the waste as LLW. + Alternatively, if ILW cannot be packaged as LLW (or in a manner that would be required for future disposal/treatment), it may be possible to identify a suitable overpack for the storage container. + Package designed to survive the timescales for decay and minimise maintenance required.	+ Storage facilities that are suitable for decay storage may already exist on-site. + Decay storing the waste for a fixed period of time (e.g. 10 years) may be a cost effective option compared to interim storing for GDF disposal (noting that the GDF is not yet available). + The decay time required may align with planned site end states and hence UK policy. + Waste is decayed to a lower category.	+ Demonstrate that decayed waste is suitable for onward management at lower category (i.e. disposal or treatment). + Demonstrate that waste is suitable for off-site transport. + Decay store records suitably kept and maintained to support post decay 'reassurance' re-characterisation.	+ New treatments or disposal routes may exist providing a greater range of options. + Waste disposed/treated at lower category. + Diverts waste away from GDF. + GDF the default backup if treatment/disposal route fails.
Challenges to be managed or considered	– Waste properties poorly understood, necessitating some preliminary assessment prior to retrieval and characterisation. – Conditioning and/or packaging may be problematic for the proposed treatment/disposal/transport options e.g. Discrete Item WAC. – Facility may not comply with the requirements of extended storage of the waste through the period required for decay of radioactive inventory.	– Waste that has already been retrieved and contained needs to be re-assayed, hence double handling of waste. – Waste contains a mixture of short-lived and long-lived radionuclides necessitating pre-treatment. – Waste comprises large items that require pre-treatment prior to being packaged.	– Facilities would be required to sort/segregate, size reduce or condition the wastes where applicable. – Pre-treating ILW may increase risk to waste operatives. – May generate secondary ILW wastes that require management. – Any conditioning used must not foreclose the intended route for or transport of the waste.	– Requirement for passive safety forecloses management option. – Store safety case may need to be changed to accommodate a new type of package. – Packages used now may not be acceptable for future disposal/treatment. – If the timescales for decay are long, package longevity/repackaging may need to be considered. – Double handling may be inevitable if the ILW cannot be packaged for transport / disposal / treatment.	– The decay time required may exceed planned site end states and hence not be compliant with policy. – The costs associated with decay storage may be higher than those associated with interim storage for GDF disposal. – A suitable decay storage facility may need to be constructed if no such facility already exists. – If the timescales for decay are long, store longevity/rebuild may need to be considered. – Resources would be required to manage the facility for the entire decay storage duration.	– The level of characterisation required to demonstrate compliance with future management routes may be onerous or uncertain.	– The intended treatment or disposal routes may no longer exist. – The intended treatment or disposal route being developed may not have matured or been successful. – Alternative disposal / treatment routes may need to be identified.
Uncertainties affecting suitability for decay storage	– Uncertainties in retrieval dates means that waste strategy/route is less well defined and considered to be low priority. – Suitability of the waste for decay storage is completely unknown.	– Characterisation may show that the waste is close to existing disposal/treatment limits, increasing risk around its suitability for future disposal/treatment.	– The extent of pre-treatment required may be uncertain due to uncertainties in future CfA/WAC.	– The long-term handling of packages is uncertain e.g. could packages used now be handled on-site, during transport and at off-site disposal/treatment plants in the future?	– Level of risk of failing to meet a future CfA/WAC increases as the decay storage period lengthens.	– Changes to transport requirements or disposal/treatment WAC may mean that waste is no longer suitable for the route.	– Changes to transport requirements or disposal/treatment WAC may mean that waste is no longer suitable.

6. Joint Regulatory Guidance & Principles for the Storage of Radioactive Material

The separate UK policies (Sections 4.2.1-4.2.4) do not provide details of what a storage facility should look like, or how it should be operated and managed in order to comply with the policies. However, such details have been outlined in the joint regulatory guidance relating to the management of radioactive waste [6]. The joint guidance provides a compilation of the requirements of the ONR, EA, SEPA and NRW, whilst also mirroring the recommendations outlined in the IAEA safety standard [8].

The joint guidance discusses the storage of radioactive waste in detail and outlines a number of fundamental principles that should be adhered to. The fundamental principles associated with storing radioactive waste have been divided into one of the following requirements: storage of unconditioned waste, arrangements for the safe and secure storage, passive safety, multi barrier containment, storage building, inspection and maintenance, records and information management. A high level summary of the joint guidance principles are presented in Table 2. A full list of detailed principles is provided in Reference [6].

Table 2: Joint guidance principles for higher activity radioactive waste storage [6]

Requirement	Joint Guidance Principles
Storage of unconditioned waste	• Raw waste should be contained in a manner that avoids deterioration and allows retrieval for processing and eventual disposal, whilst maintaining standards of safety and environmental protection that are as close as is reasonably practicable to those for stored packaged wastes. • Periodic inspection should be undertaken where it is reasonably practicable to do so, to confirm that degradation will not affect the ability to retrieve and process the waste.
Arrangements for the safe and secure storage	• Arrangements for the safe and secure storage, for the anticipated storage period, that ensures protection of people and the environment is required in all circumstances. • Arrangements should be applied in the context of a suitable programme for managing such wastes to a point where responsibility for the wastes can be discharged through final disposal or suitable alternative storage. • Arrangements should have regards to: passive safety, multiple barrier containment, storage facility design, storage capacity, inspection criteria, maintenance, inspection and retrieval and records.
Passive safety	• Radioactive waste should be stored in accordance with relevant good engineering practise and the requirements of passive safety. The principles of passive safety are the same as those quoted in the IAEA safety guidance [8], which has been reproduced in Section 4.1 of this report. • Passive safety requires radioactive wastes to be in a form that is physically and chemically stable and stored in a manner that minimises the need for control and safety systems. • Passive safety covers both the waste package itself and the storage conditions.

Requirement	Joint Guidance Principles
	• It is recognised that it may be necessary or advantageous for some active systems to be in place, for example control of environmental conditions within the store. In such cases, the systems should be designed for minimum maintenance, and, in the event of failure, immediate repair/ replacement should not be necessary in order to ensure continuing safety of the storage facility and its contents. • Licensees should aim to apply the requirements for passive safe storage within a framework of reasonable practicability and cost-effectiveness. • As part of a store's safety case, licensees may employ probabilistic safety assessment methods to demonstrate that the risk from the facility is acceptably low. • However, probabilistic safety assessments should not be used to defend noncompliance with current relevant good practice or good standards of engineering.
Multi-barrier containment	• A multi-barrier approach should be adopted to provide effective containment and protection of the environment. • The physical barriers include the nature of the waste itself, any material that may be used for encapsulation, the waste container and the storage building or structure, each of which should be designed to provide effective containment and prevent leakage of radioactive material. • The multiple barrier containment provided by the storage building or structure is particularly important in consideration of the storage of unconditioned wastes (e.g. prevention of leakage to ground of raw waste).

Storage building	• The storage building is the outer physical barrier to the release of radioactivity to the environment.
	• Where safety and protection of the environment is dependent on the performance of the storage building or structure as a barrier, specific design criteria with respect to external hazards, will be relevant.
	• Stores should be located and designed to reduce the potential of water ingress.
	• The radioactive waste storage facility should be designed on the basis of assumed conditions for its normal operation and assumed incidents or accidents and should fulfil the following fundamental safety functions: acceptable sub-criticality margins, where necessary.
	    • containment of radioactive material
	    • optimised radiological protection of operating personnel, the general public and the environment via appropriate shielding and control of the release of any radioactivity
	    • adequate arrangements for handling and stacking of waste packages
	    • and, removal of heat, where necessary.
	• Storage facilities should be designed in accordance with relevant good engineering practice and to enable radioactive waste to be stored in a passively safe condition, taking account of normal and accident conditions.
	• The design lifetime of the storage facility should align with the expected storage period.
	• The storage environment should maximise waste package life.
	• Appropriate monitoring systems and alarms should be provided but there should be no requirement for continuous human presence or supervision at the store to

Requirement	Joint Guidance Principles
	ensure safety. • The storage building should be resistant to foreseeable hazards e.g. seismic activity, high winds and flooding. • There should be no need for prompt remedial action following abnormal conditions. • Reserve storage capacity should always be available. • Waste Acceptance Criteria should be set for the storage facility that include consideration of future disposal requirements or planned management strategies, and arrangements put in place to assure compliance. • Contingency plans should be prepared for packages that do not meet the acceptance criteria for the storage facility.
Inspection and maintenance	• Storage facilities should be maintained and inspected. • This should include both preventative and corrective maintenance. • A waste package monitoring programme should be developed and implemented. • Remedial action should be implemented for waste packages that show signs of degradation. • The storage facility should facilitate the retrieval of all waste packages for inspection, remedial treatment and transfer elsewhere for further storage or final disposal.
Records and information management	• Information and records that might be required now and in the future for the safe management of radioactive waste should be assembled and preserved. • Storage of radioactive waste may last for at least 100 years. Comprehensive information and records need to be assembled as part of the storage arrangements. Records should be kept in such a way that sufficient information can be extracted for both current and future needs for each individual waste package. They need to be securely retained and to be accessible when required.

6.1. Applicability of Radioactive Waste Storage Principles to Decay Storage & Decay Storage Specific Principles

There appears to be no separate UK policy on decay storage, although a number of the guidance documents that have been produced for general storage also include information relating to the implementation of decay storage. The available guidance includes:

- IAEA Safety Standards – Storage of radioactive waste [8]
- NDA Industry Guidance Interim Storage of Higher Activity Waste Packages – Integrated Approach [3]
- RWM Geological Disposal - Review of Alternative Radioactive Waste Management Options [1].

Each of the guidance documents recognises that the storage of radioactive waste, specifically for the purposes of allowing the radionuclides to decay, is a viable management route. Moreover, many of the principles outlined in Table 2 are directly applicable to decay storage, which emphasise the requirement for safe and secure storage for the entire duration.

However, there are some subtle differences in the assumptions surrounding decay storage and interim storage that earlier sections of this review paper identify. Firstly, the timescales required for decay storage may be different to those of interim storage depending on the constituent radionuclides that need to decay. Moreover, decay storage assumes that following the storage period, the waste would be diverted from the GDF, such that there would be a requirement to demonstrate that the waste can be cleared from regulatory control, or meets the CfA, or WAC, of the intended disposal or treatment / processing facility.

On this basis some additional principles, or considerations, specific to decay storage (that have not been captured in Table 2) are noted in Table 3.

Table 3: Additional principles specific to decay storage

Requirement	Additional principles specific to Decay Storage	Ref
Removal from regulatory control (clearance of material), or consign to onward disposal or treatment/processing facility	• The radiological and non-radiological profile of the waste (including any conditioning and packaging) needs to be suitable for the treatment and/or disposal route. • The radiological and non-radiological profile of the waste (including any conditioning and packaging) needs to meet transport requirements. • Representative measurements should be carried out on samples taken and analysed prior to the onward consignment of waste.	[8]
Storage period	• The decay storage period should be long enough to reduce the initial activity to levels required for its onward, non-GDF management. • Waste designated for decay should be segregated from other waste in the storage facility, from the point of generation up to the end of the decay storage period and its final disposal. • Storage facilities and packaging solutions must address the full decay storage period and end-state dates for the site. • Storage periods exceeding storage periods for GF disposal need to be considered against the requirement for early solutions.	[8]

7. Examples of Decay Storage

7.1. Decay Storage in the UK

This section outlines some examples of decay storage implementation of higher activity waste in the UK. As mentioned previously, a number of waste producers in the UK have actively adopted this management strategy, with high-level details being available in the open literature.

Chapelcross Tritiated ILW

The Magnox site at Chapelcross plans to store its tritiated ILW waste in sealed containers. The containers will comprise of 500 litre stainless steel drums and a temporary storage vessel (overpack). The intention is to store the waste for approximately 150 years before it can be disposed as LLW [3].

Magnox ILW Desiccant

The Magnox integrated and waste management strategy [15] that was published in 2016 states that ILW desiccant material from three sites (Bradwell, Chapelcross and Hunterston A) will be transported to LLW Repository Ltd for eventual disposal following a period of decay storage. Mercury and rotary pump oil from Chapelcross will also be decay stored before being consigned to LLWR. The overall strategy is presented in Figure 1.

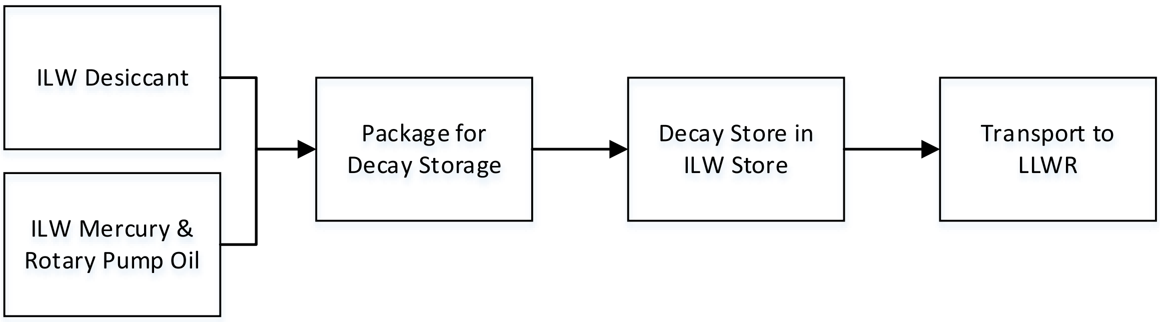


Figure 1: Overall strategy for decay storing ILW (reproduced from reference [15])

Storage facilities will be constructed on each of the Magnox sites to provide storage capabilities for HAW arising during preparation for Care and Maintenance. The first of the Magnox storage facilities in Scotland is already operating at Hunterston A [16].

A Joint Waste Management Plan has recently been published [17] that provides an overview of Magnox LLW management arrangements and transformational activities. The latter are activities that could provide a step change in the management of LLW and recognises that decay storage guidance and the development of principles could provide a benefit.

Rosyth Dockyard Ion Exchange Resins

There is approximately 30m^3 of ion exchange resin waste at the Rosyth Royal Dockyard in Scotland. No future arisings are expected at the site and the waste is included in the Scottish Policy and Strategy [16]. The current baseline position for the waste at Rosyth Royal Dockyard is for it to be decay stored until a disposal route becomes available [3].

Dounreay Tritiated Steel

Dounreay has HAW tritiated steel. The current strategy is to decay store the untreated material in Half-Height ISO containers in an unshielded ILW store until the waste has decayed to LLW. For some waste, it is estimated that this will take 45 to 50 years [3].

7.2. International Storage Examples

Section 7.1 demonstrates how decay storage is being considered by a small number of waste producers in the UK. However, some international examples of storage are provided in Appendix 1 covering one further specific example of decay storage and general (interim) storage. A number of the storage principles outlined in Section 6 are being followed by each of these international storage examples. Table 4 summarises the storage principles being adopted by each of these international examples, with further details presented in Appendix 1.

Table 4: Summary of the storage principles implemented by international storage facilities/approaches

Storage Facility/Approach	Country	Storage Principles being Implemented
'Decay in Storage'	United States	• Multi-barrier containment of unconditioned waste (offered by the inner liner and container). • Protection of facility occupants through appropriate packaging/containment during the period of decay storage. • Consideration of the appropriate storage period to ensure the activity has decayed sufficiently. • Protection of the public through careful survey/monitoring of the waste after storage and before it is disposed. • Recording of information during storage that will be required in the future for safe management. • Recording of information after the storage duration to support disposal. • Monitoring of the waste to assess suitability to remove from regulatory control/clearance.

Storage Facility/Approach	Country	Storage Principles being Implemented
COVRA (general interim storage)	Netherlands	• Purpose built storage facilities for low/medium level waste and high level waste storage. Both are designed to operate for the entire storage period. • Storage buildings provide physical protection, or barrier to the packages and isolation from the environment or people. • Facility has arrangements for package handling and stacking. • Inspection of packages. • Labelling of packages to support record and information management. • Facilities engineered with accident conditions in mind / resistant to foreseeable hazards (e.g. gas explosions, floods, earthquakes etc.).
ZWILAG (general interim storage)	Switzerland	• Purpose built storage facilities for low/medium level waste and high level waste storage. Both are designed to operate for the entire storage period of 30-40 years. • Storage buildings provide physical protection, or barrier to the packages and isolation from the environment or people. • Storage environment controlled. • Facility has arrangements for package handling and stacking e.g. remote handling. • Records and information management through provision of a centralised inventory and inventory information for each individual package. • Measurements undertaken to support records management. • Waste package monitoring programme.
Bruce Nuclear Power Site (general interim storage)	Canada	• Purpose built storage facility designed to operate for the entire storage period of 50 years. • Waste is stored in an engineered structure, isolated from the environment. • Liquids immobilised before being placed in the store (passive safety). • The store facilitates retrieval of waste packages.

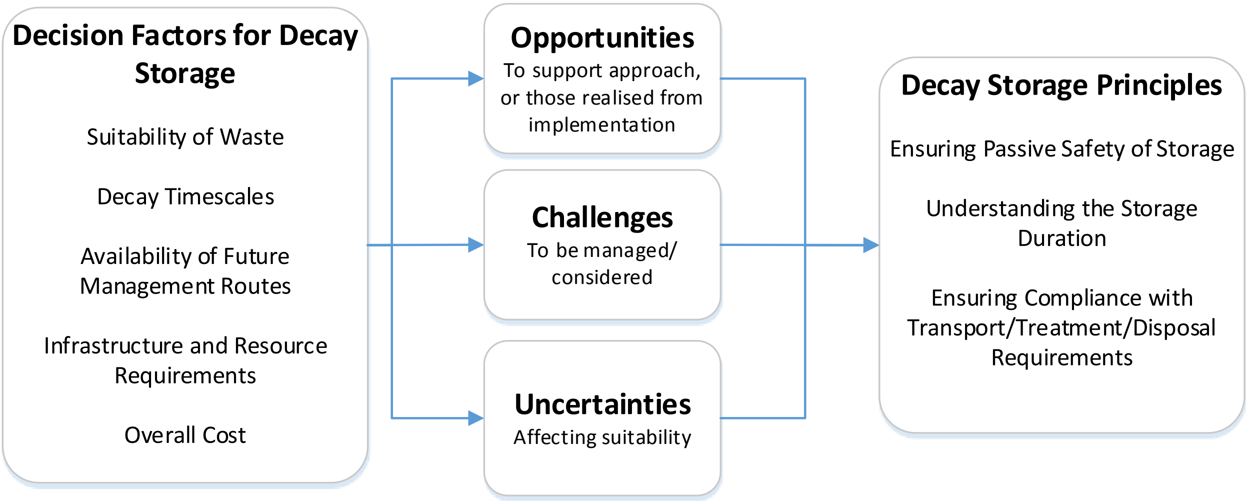
8. Desk Review Summary

Decay storage has been recognised by the international community and the UK regulators as being a credible management route for certain ILW. The ultimate aim of decay storage in the UK would be to allow waste to be managed at a lower category and reduce the volume of waste disposed to the GDF. However, waste producers may need to consider a number of factors when deciding on the suitability of the approach. Some factors have been identified in Section 5 and have been termed ***decision factors.*** These include: the suitability of the waste for decay storage, decay timescales, availability of future management routes, infrastructure and resource requirements and overall cost and benefit. Waste producers may have additional decision factors that need to be considered for certain waste streams, or sites.

When considering these decision factors, a number of opportunities, challenges and uncertainties may be identified, which ultimately determine the suitability of the approach and underpin whether decay storage is appropriate. If having considered the opportunity balanced with the associated challenges and uncertainties, decay storage is identified as a suitable management approach, then waste producers will need to comply with a set of principles to ensure that the storage of radioactive waste is undertaken in accordance with the relevant regulatory requirements. A number of guidance documents have been published to assist waste producers in making appropriate arrangements for the storage and decay storage of ILW. A review of these guidance documents has allowed some high level ***principles*** to be identified to which waste producers would need to adhere when decay storing radioactive waste on site. The key principle associated with any radioactive waste storage is that it is addresses concerns for passive safety. This principle is broad and covers the whole storage system, comprising the waste material, containment, storage facility, storage environment, physical barriers and the management of the system. In addition, a high level principle for decay storage would be to ensure compliance with treatment and/or disposal requirements at the end of the storage period, along with an understanding of the duration of storage required to achieve the identified level or radioactive decay.

Figure 2 summarises the relationship between the ***decision factors***, the opportunities, challenges and uncertainties identified through the decision factors, and the high level ***decay storage principles*** that need to be underpinned if this management approach is to be adopted for a waste stream.

Figure 2: Relationship between decision factors, opportunities, challenges, uncertainties and principles



This report has been prepared in support of a stakeholder workshop, which aims to identify and discuss the approaches to decay storage and any additional decision factors, opportunities, challenges and uncertainties and principles relevant to support this management approach.

Appendix 1: International Examples of Storage Implementation

Examples of radioactive waste storage are provided in the following sub-sections and have been presented to illustrate the principles being used. It should be noted that three examples focus on general storage rather than decay storage specifically. Limited information relating to the implementation of decay storage is available in the open literature. The reasons for this were two fold; firstly, the lack of clear treatment or disposal routes for many of the wastes meant that decay storage was not clearly stated as part of a management approach. However, some of the strategies being adopted by certain organisations (e.g. the Centrale Organisatie Voor Radioactief Afval in the Netherlands) for the storage of low and medium level radioactive waste could be considered as being decay storage and analogous to the approach being considered in this project. The second reason for the limited international decay storage review may be due to differences in terminology. For example, the term ‘decay in storage’ is used by the United States. Differences in terminology between different countries and organisations undoubtedly affect the number of clear examples on international decay storage available within the open literature.

Decay in Storage (United States)

Decay in storage is a term used in the United States for the storage of a radioactive by-products with a half-life equal to, or less than 120 days before it can be disposed without regard to its radioactivity providing certain conditions are met [18]. These conditions include:

- The radioactivity of the material cannot be distinguished from the background radiation level with an appropriate radiation detection survey meter set on its most sensitive scale and with no interposed shielding.
- All radiation labels are removed, or obliterated, except for radiation labels on materials that are within containers and that will be managed as biomedical waste after they have been released from the licensee.
- The licensee retains a record of each disposal.

Decay in storage is largely applicable to short-lived radionuclides used in medical research and is applicable to P32, P33, S35, Cr51 and I125 [19]. There are rigorous procedures in place for the regulation of decay in storage and to prevent the accidental release, or disposal of material. Procedures published by the Weill Cornell Medical centre include [19]:

1. Once a waste container is full:

    - Gather the inner liner and tightly wrap it closed with tape.
    - Place a cover on the container and seal it to prevent access to the contents.
    - Complete a waste log attached to the container, listing chemistry, radioisotopes, activities and dates.
    - Record the date when the container was sealed.
    - Radioisotopes must decay-in-storage for 10 half-lives before removal.

2. After 10 half-lives have passed:

- Remove the cover of the container.
- Remove the inner liner.
- Check for any activity above background with a calibrated survey meter.
- Place an inner liner into the appropriate waste stream (biological, chemical, non-hazardous).
- Complete the decay in storage record, entering disposal date, survey results, instrumentation used, and operator name.
- The waste log/decay-in-storage record must be kept for at least three years.

These procedures represent just one example of how decay in storage is managed in the United States. However, the procedure clearly adopts many of the principles identified in Section 6, which includes multi-barrier containment, clear labelling and record keeping, isolation of material from the public/other laboratory operatives and monitoring.

COVRA (Netherlands)

The Central Organisation for Radioactive Waste (Centrale Organisatie Voor Radioactief Afval, or COVRA) is the only company in the Netherlands that is qualified to collect, process and store radioactive waste [20]. The mission of the organisation is to provide continuous care for radioactive waste in the Netherlands up to the moment that the radioactive material has completely decayed and a safe, stable situation is created. The Dutch policy on radioactive waste management is to store all types of radioactive waste above ground for a period of at least 100 years. After this storage period, a decision will be made on whether to dispose the waste. COVRA also acknowledges that once the storage period has ended, international solutions may be available, or new techniques might have been developed to manage the waste. In this context, there are many parallels between the Dutch policy on radioactive waste storage and decay storage.

Low and Medium Level Waste Storage

Low and medium level waste[10] are stored is a storage facility known as Laag- en middelradioactief afval OpslagGebouw, or LOG. This facility has four storage areas linked by a central reception bay. Conditioned waste is unloaded within the central corridor and taken to the storage areas by forklift trucks, which then stack the conditioned waste packages.

[10] Low and medium level radioactive waste comprises: gloves, laboratory glassware, clothing, resins, syringes, sealed sources of radiation, smoke alarms, plastic wrap, pumps and pipes, contaminated scrap, animal carcasses from research experiments, liquids, filters and sediments. The demolition of laboratories where radioactive materials have been used and the dismantling of nuclear power and research reactors also yield radioactive waste.

The packages are arranged in aisles with sufficient space being maintained between the aisles to allow inspection. All packages are numbered, such that information relating to the waste can be retrieved when required.

New storage facilities are planned for the future, with the site having room for twelve extra storage buildings.

Solid radioactive material produced during the processing of ores is stored in the Container Storage Building. This waste is not conditioned, but is stored in an unconditioned form in standard containers.

High Level Waste Storage

The HABOG storage facility is used for higher level waste[11]. The facility is isolated from the environment and is kept under close monitoring and control. The walls of the facility are 1.70 m thick to provide radiation shielding. The building is designed to withstand any extreme external influences, such as: hurricanes, gas explosions, earthquakes, floods and airplane crashes. In this way safe storage is guaranteed [20].

ZWILAG (Switzerland)

The Swiss disposal concept involves disposing radioactive waste in repositories located in suitable rock formations. No such repository exists at the current time, such that radioactive waste must be kept in interim storage for 30 to 40 years until it no longer emits any heat. For low and medium level waste, interim storage bridges the gap until the commissioning of a deep geological repository [21]. The Swiss policy bears many similarities to that adopted in England (Section 4.2.1).

All categories of radioactive waste generated in Switzerland are processed and temporarily stored in the ZWILAG facility and the neighbouring Federal interim storage facility, respectively. These wastes primarily comprise:

- Operational waste and spent fuel rods from nuclear power plants.
- Waste originating from the reprocessing of spent fuel rods.
- Radioactive medical, industrial and research waste.

The neighbouring Paul Scherrer Institute has been used for many years as an interim storage facility for radioactive waste. The close proximity of the Institute has several advantages: by combining the waste processing plants and central interim storage facility, the waste can be

[11] High level radioactive waste consists of nuclear fuel elements that have been used in research reactors, waste from the production of nuclear medical isotopes and reprocessing waste from nuclear power reactors. In the Netherlands this concerns the research reactors in Petten and Delft and the nuclear power reactor in Borssele. This waste is vitrified before being placed in the store.

optimally combined and the number of transfers reduced. In addition, the waste can be optimally monitored and controlled [21].

The facility has separate storage halls for low and medium level waste and high level waste. The storage building for low and medium level wastes has storage capacity for 384 twenty-foot storage containers. The storage containers are filled with conditioned waste ready for final storage and are stacked one on top of the other in the storage shafts by remote control. The solid construction of the building shields the waste and protects it from the external environment. The individual storage shafts in the storage building are covered by solid concrete lids [21].

The storage building is managed in accordance with the latest principles of radiation protection, which include [21]:

- The reception, unloading and storage areas are separate.
- The waste packages are handled remotely.
- The contents of the containers destined for storage can be checked at monitoring stations.
- There is a centralised inventory.
- Moreover, the inventory for each location and of the contents of each individual container are maintained.
- The condition of the stored casks and containers is also checked regularly.
- Environmental controls are present:
  - Continuous gas monitoring is undertaken by a gas warning device installed in the exhaust air vents. This monitors the concentration of hydrogen and methane.
  - Continuous monitoring of the storage building temperature.

Ontario (Canada)

All low level radioactive waste in Canada, which encompasses all forms of radioactive waste except spent nuclear fuel (which is high-level waste) and waste resulting from uranium mining, milling and mill tailings, is in storage. The method of storage varies considerably, depending upon when and where the waste was created [22].

Historic waste has been poorly managed and has included depositing waste on municipal landfill sites, vacant land and near-surface burial sites. These approaches led to contamination issues (chemical and radiological) [22], which does not comply with the principles of storage relating to passive safety, multi-barrier containment and protection of people and environment (Section 6). A more concerted effort has been made in recent years to improve waste management procedures, with waste now being stored at nuclear sites. A variety of different storage facilities are in use today depending on the radioactivity of the waste and include: warehouses, quadricells and trenches [22].

A significant proportion of the low level waste is generated at the 20 nuclear power reactors operated by Ontario Hydro and from the research laboratories of Atomic Energy of Canada Limited (AECL). All of this waste has been stored at Ontario Hydro's Bruce Nuclear Power

Development site, or the Chalk River Laboratory site of AECL, to avoid the problem of having many small sites.

The Bruce Nuclear Power Development site is located 200 km from Toronto. In storing the waste at the site, four basic principles are followed [22]:

1. The facilities are designed to last a maximum of 50 years and materials must be retrievable from them.

2. Radioactive materials cannot be placed directly in the earth, but must be in an engineered structure.

3. Only solids are placed in storage; liquids must first be immobilised to ensure they do not spread into the environment.

4. Waste storage is recognised as a temporary stage of management pending future disposal. No permanent disposal method for low-level radioactive waste has yet been implemented.

The above principles align with those in Section 6 by ensuring: the suitability of the store for the intended storage period, retrieval and passive safety.

9. References

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2 NDA Higher Activity Waste Treatment Framework, Document Ref: 23792960, October 2015

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