Industry Guidance

Interim Storage of Intermediate Level Waste Packages – Integrated Approach

August 2026

Contents

Foreword

In delivering the NDA mission we will continue to generate and package radioactive waste arisings over a period of many decades. Hence, the packaged waste is a major investment of high intrinsic value in terms of environmental, safety and security benefit.

Waste storage plays an important role in the radioactive waste management lifecycle and provides a safe, secure environment for waste packages awaiting final disposal. This position is a key part of UK Government and Devolved administrations' radioactive waste management policies, with the overarching approach to storage set out in Nuclear Decommissioning Authority (NDA) Strategy and the NDA Radioactive Waste Strategy. Storage systems also provide a safe and secure environment for waste packages awaiting further conditioning. This is reflected in the Prime Minister's strategic steer to the nuclear sector following the 2025 Nuclear Regulatory Taskforce's Review, which states that:

> *"The safe and secure management of spent fuel and radioactive waste remains a matter of public trust and national responsibility. Progress towards a Geological Disposal Facility (GDF), alongside the development of modern interim storage, is an important part of this journey. Regulators should work with dutyholders to ensure that well evidenced treatment, packaging and storage solutions are implemented in a timely manner, providing clarity and predictability so that projects may plan with confidence."*

The storage system effectively provides containment for the prevention of releases of radioactivity to the outside environment. A system of robust storage arrangements provides high confidence that packages stored in a final form will be disposable at the end of the storage period. Our strategy ensures that storage programmes support the safe and secure storage of radioactive wastes for a period of at least 100 years, providing resilience to variance in the availability of disposal routes.

The Store Operations Forum (SOF) brings together NDA strategic leads, Nuclear Waste Services (NWS), waste producers and store operators. It is designed to engage, coordinate and drive strategy development through shared learning concerning the storage of containerised waste across the UK prior to disposal and ensuring that this 'Industry Guidance' document represents good practice. We promote the development and use of our storage facilities as a group-wide system through Group Action Plans to deliver collaborative efforts to drive efficiency across our Operating Companies and the wider industry.

It is expected that our Operating Companies will implement the updated Guidance to maintain and improve existing waste storage systems and when planning new stores. Other organisations will continue to be able to freely access and use the Guidance.

It is intended that the Guidance remains fit-for-purpose through continual improvement, and it will be updated as appropriate. If you have any comments on the Guidance, please email these to **strategy@nda.gov.uk**.

Matt Buckley, Strategy Manager for Treatment and Storage, NDA

Abstract

A cross-industry team assembled by the Nuclear Decommissioning Authority (NDA) has developed this Industry Guidance on the interim storage of packaged intermediate level radioactive wastes that require isolation and containment provided by geological disposal (or near surface disposal, where applicable) (hereafter referred to as intermediate level waste (ILW)). From 2009 to 2011, the project team engaged with the industry through workshops, commissioned development work and interacted with store operators and regulators. Issue 2 of the Guidance was published in 2012. The Guidance has subsequently been curated by the Store Operations Forum (SOF), and a revised version (Issue 3) was published in January 2017, with two inter-related components (the integrated approach and extended summary) consolidated into a single document to facilitate accessibility and ease of use. In addition, Issue 3 widens the scope to cover a broader range of waste package types, including stainless steel, mild steel and concrete containers. Issue 4 included considerations relative to safe containerised storage pending future treatment, including a new dedicated Approach (A4). This document, Issue 5 adds an additional Approach (A5) and extends the scope to cover sustainability aspects of store design and maintenance and Approach (A30) for records management for the storage system.

It is intended that this Guidance will be used by those involved in managing any aspect of current and future UK stores for packaged ILW. Whilst ILW is the primary focus of this document, it is recognised that the guidance may also apply in the management of some low level wastes (LLW) that are not destined for disposal in a LLW disposal facility and are packaged and managed in much the same way as ILW.

The Guidance seeks to cover the main significant technical issues currently identified from interim storage of packaged ILW, be practicable in implementation, and relevant to all UK storage system designs. It provides references to additional guidance and underpinning work including Research and Development (R&D).

The Guidance is comprised of four primary sections covering the key elements of a robust approach to interim storage. These sections are package performance and design; store performance and design; operation of the storage system and provision of assurance of the system over an intergenerational timescale.

To accommodate the diversity of UK ILW, the Guidance describes six common principles and 30 specific approaches covering the lifecycle of interim storage and variation in waste properties. When these are implemented as a coherent set, the Guidance forms an ‘integrated approach’ to interim storage that may be especially useful to the design and planning of new stores. When specific approaches are applied, in the context of an existing storage system, then the Guidance may be used to improve existing arrangements through comparison with identified good practices and toolkits based on operational feedback.

A Glossary, together with definitions of abbreviations and acronyms, is provided at the end of the document to facilitate use of the Guidance.

1. Introduction

1.1 Background

The Nuclear Decommissioning Authority's (NDA's) review of the UK's arrangements for interim storage of Higher Activity Waste (HAW) (i.e. wastes that require isolation and containment provided by geological disposal (or near surface disposal, where applicable)) was published in March 2009 [1]. The review addressed the concluding recommendations from the Committee on Radioactive Waste Management (CoRWM) to Government in 2006 [2], notably 'Recommendation 2', which stated that:

"*A robust programme of interim storage must play an integral part in the long-term management strategy.*"

This recommendation on interim storage has been subsequently affirmed in the Implementing Geological Disposal – Working with Communities Policy Paper [3] where the UK Government re-confirmed that the long-term management policy is disposal at a Geological Disposal Facility (GDF), preceded by safe and secure interim storage and supported by ongoing research. The policy paper sets out the framework for achieving this. The UK policy framework for managing radioactive substances [4], published in 2024, aligns with the 2006 CoRWM recommendation of geological disposal following a period of interim storage for England, Wales and Northern Ireland; as well as the inclusion of concepts for near surface disposal that would also follow a period of interim storage.

The Scottish Government has published a separate Higher Activity Radioactive Waste Policy in 2011 [5]. This states that *"The long-term management of higher activity radioactive waste should be in near–surface facilities..."* and that storage facilities should have the capability to last for at least 100 years, with the capability of extension beyond this. The Scottish Government has published a strategy for implementing its policy [6]. Scottish policy on the duration of storage is broadly consistent with the position for interim storage facilities in England and Wales, where there is a requirement for safe and secure storage of waste in stores for a period of at least 100 years [4]. There is no ILW in Northern Ireland (NI) and no plans for geological disposal in NI.

Following their high–level recommendations in 2006, CoRWM published a more detailed report on interim storage in 2009 [7], recommending that the NDA should implement greater UK-wide strategic co-ordination of the conditioning, packaging and storage of radioactive waste. The UK Government [8] and the Devolved Administrations, accepted this recommendation from CoRWM, highlighting the need to meet the high safety, security and environmental standards required by the regulators. They also noted the formation of an Integrated Project Team (IPT) led by the NDA, made up of its Site Licence Companies (SLCs) and other waste owners to examine conditioning, packaging and storage of ILW. The IPT considered many of the issues arising from the two reviews [1, 7], and led to publication of the Industry Guidance – referred to as the 'Guidance' from this point. Following launch of Issue 2 of the Guidance, in 2013 CoRWM commended progress in the area of interim storage [9], stating that:

"The Committee considers that there have been substantial improvements over the last three years, driven largely by the Industry Guidance project, which has been very successful and worthwhile."

Today, the Store Operations Forum (SOF) own and curate the Guidance, with support from the Storage IPT. NDA remains the sponsor of the Guidance and the SOF is encouraged to bring forward suggested Research and Development (R&D) needs through the Nuclear Waste and Decommissioning Research Forum (NWDRF). The Storage IPT focusses on strategic management of the storage system to ensure the right storage capabilities are available to support the NDA mission and manages the interfaces between the storage, treatment and disposal stages of the waste lifecycle.

1.2 Guidance Overview

The Guidance covers the currently recognised technical challenges arising from interim storage of radioactive waste packages, and aims to be practicable in implementation, and relevant to most waste package and store designs. It recognises that while some of the issues are short-term in nature, many are longer-term and span inter-generational timescales and require a risk management approach.

The Guidance provides an Integrated Approach to the management of ILW storage, and it describes principles, approaches, good practices, and toolkits as an aid to current and prospective organisations acting as store operators. 'Store operators' refers to licensees with direct responsibility for managing the storage system across any part of its lifecycle. The Guidance is also relevant to waste producers to ensure that waste packages are compatible with store designs and vice versa.

The topics considered in the Guidance are largely those that were originally covered by the NDA's Storage Review [1], notably those in Chapter 5. These topics have been subject to considerable engagement with industry stakeholders. Since 2010 the SOF, comprising representatives of current and planned UK stores, meets annually and has provided oversight of the Guidance covering operational experience – see subsection 2.3.2. The interface with technological development is described in subsection 2.3.1. The SOF also facilitates sharing of knowledge, experience and opportunities for improvement in the area of waste storage.

The strategic need to provide adequate storage capacity to support future disposal in the UK was a major topic in the 2009 CoRWM and NDA reports, and is discussed in the NDA's Strategy [10] and NDA's Integrated Waste Management Strategy [11] . Risks, issues and opportunities continue to be monitored, which informs the scope delivered through the Storage IPT, an integrated project team that seeks to optimise the use of our current and future stores.

1.2.1 Objectives

The objectives of the Guidance are to provide:

a. Standardised and practicable methods (i.e. approaches) and options for solutions (i.e. toolkits) for store operators across the following issues, which were raised in the CoRWM and NDA reviews, concerning:

    I. package performance criteria – see subsection 2.4.1;

II. store environmental controls – see subsection 4.3;
III. avoiding the need for package reworking – see subsection 5.3;
IV. optimisation of store longevity – see subsection 5.6; and
V. package monitoring & inspection – see subsection 6.2.

b. Examples of good practice to inform future store designs and operations, and where feasible, improve current store operations – see Section 7;
c. An integrated approach, which can be used to demonstrate to the licensees, regulators, and the waste owner that packages will remain safe and disposable (or safe and retrievable for finishing, if an interim product) during storage, including:

I. assurance that waste packages and key store life-limiting components continue to meet the nuclear safety case;
II. assurance that waste packages remain readily exportable for eventual disposal, finishing (if applicable) or continued storage elsewhere;
III. assurance that licensees will undertake sufficient auditing and knowledge management to demonstrate compliance with relevant License Conditions and support Best Available Techniques (BAT)/ Best Practicable Means (BPM) and Best Practicable Environmental Option (BPEO) studies for packaging and storage of wastes; and
IV. assurance that store and package records are managed to demonstrate continued disposability of waste packages.

1.2.2 Audience

The intended audience, which is assumed to have some pre–existing understanding of the issues surrounding storage, for the Guidance is:

- Licensees, their store operators/ designers;
- NWDRF and its working group covering storage - see subsection 2.3.1;
- NDA;
- Other owners of ILW; and
- Regulators.

1.2.3 Changes Since Last Issue

The following significant changes, since Issue 4 was published in January 2021, are highlighted:

- New principle ‘effective records management’ included.
- Addition of Approach A5: Sustainability and Approach A30: Records Management.
- Section 3: Package Performance and Design and Section 6: Storage System Assurance revised along with associated approaches.

1.2.4 Future Issues

Future issues of the Guidance will be sponsored by the Integrated Waste Management team within NDA Strategy. The document management process for the Guidance is described in subsection 2.3.3.

1.2.5 Scope

The Guidance covers the interim storage of packaged ILW, across the UK, in surface facilities before its eventual transfer to a disposal facility or another storage facility. A list of current and planned stores, in the UK, is provided in Section 8.

The following aspects define the scope of the Guidance:

a. **Surface stores** which have been, or will be, purpose built or adapted to store ILW packages. Near-surface storage and its associated requirements may be considered in the future issues of this Guidance;
b. **Storage periods of the order of 100 years**, within a store, with consideration beyond this as appropriate [3, 10, 11]. In Scotland, where Government policy requires provision for around 300 years of storage, interim storage beyond 100 years would be met by stores being maintained, refurbished or replaced as appropriate throughout the storage period, the design lifetime being at least 100 years for new store build [6]. This is in alignment with Nuclear Waste Services (NWS) requirements that waste packages shall maintain their integrity for 150 years following their manufacture and should maintain their integrity for 500 years. Integrity of the waste package refers to maintaining functional performance requirements;
c. **Waste packages** within surface stores, which are subject to assessment through NWS's Assurance of Disposability (AoD) process, and which:
    I. have been or are planned to be conditioned, (including for long-term storage of interim products - see Approach A4), for disposal; or
    II. although currently unconditioned, and not currently covered by bespoke plans for conditioning, may require future conditioning, e.g. for disposal; and
    III. have been demonstrated to be compatible with the requirements for safe transport to and disposal in a GDF.
d. **Waste packages** which may be disposed of to the near-surface environment, including those mainly comprising short-lived radionuclides that are being stored to take advantage of radioactive decay.

Limited additional applicability

In addition to being informed by facilities outside the defined scope above, the Guidance might also find useful application, in part, to the long-term stores for high level waste (HLW) and LLW packages. The Guidance might also have some useful application to stores containing dry spent fuel, nuclear material and Depleted Natural and Low Enriched Uranium (DNLEU), however this guidance has been developed to meet the specific management requirements for ILW.

Principal exclusions

This Guidance does not cover the following waste storage and long-term management contexts, as their management requirements and ongoing processing steps are different:

- management within geological disposal facilities such as a GDF;
- short-term stores for LLW packages;
- raw and unretrieved radioactive waste which remains in an unpackaged state;
- stores, or ponds, containing wet spent fuel, nuclear materials and precursor products; and
- non-radioactive waste storage.

It should also be noted that there is only limited consideration of socio–political and economic issues within the Guidance. These issues may, in addition to the technical issues considered, strongly influence decision making.

1.3 Principal Legislation, Standards and Guidance

1.3.1 International Obligations

The following International Atomic Energy Agency (IAEA) Safety Standards are highlighted as fundamental requirements with reference to interim storage:

- General Safety Requirements (GSR) Part 5 [12] which establishes the safety requirements that apply to all facilities and activities that are involved in the management of radioactive waste before disposal;
- Regulations for the Safe Transport of Radioactive Material (SSR-6) [13], which establishes standards of safety to provide an acceptable level of control of the radiation, criticality and thermal hazards to persons, property and the environment, that are associated with the transport of radioactive material. For spent fuel additional guidance is given in IAEA-TECDOC-1938 [14];
- Storage of Radioactive Waste WS-G-6.1 (2006) [15];
- Leadership, Management and Culture for Safety in Radioactive Waste Management [16];
- Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [17];
- GSR Part 4, Safety Assessment for Facilities and Activities [18];
- GSR Part 6, Decommissioning of Facilities [19];
- Specific Safety Guide (SSG) Seismic Hazards in Site Evaluation for Nuclear Installations [20]; and
- Specific Safety Requirements (SSR) Site Evaluation for Nuclear Installations [21].

An extant technical report on interim storage [22], which provides guidance on various technological aspects of radioactive waste package storage, should also be noted.

More facility-specific requirements are set out in a report prepared by the Western European Nuclear Regulators' Association (WENRA) [23] which details Safety Reference Levels (SRLs) for radioactive waste and spent fuel storage facilities.

1.3.2 UK Legislation

The following fundamental legislation relevant to radioactive waste management, including interim storage, is highlighted:

- Nuclear Installations Act 1965 as amended (NIA 65) [24] and standard conditions applied to nuclear site licences;
- Health and Safety at Work etc. Act 1974 (HSWA) [25];
- In Scotland, the Environmental Authorisations (Scotland) Regulations 2018 (EASR) [26]
- In England and Wales, the radioactive substances regulation form part of the Environmental Permitting Regulations (EPR) 2016 [27], as amended in 2018 [28];
- The Ionising Radiations Regulations 2017 (IRR17) [29]; and
- The Nuclear Industry Security Regulations 2003 (NISR 2003) [30].

1.3.3 Regulatory Guidance

The Regulatory 'Joint Guidance' on radioactive waste management [31] is derived from internationally agreed standards and guidance, national legislation and regulatory principles contained in the:

- The Office for Nuclear Regulation's (ONR's) Safety Assessment Principles (SAPs) [32], and Technical Assessment Guides (TAGs) which cover both new and existing storage facilities; and

- Environment Agency’s (EA’s) Radioactive Substances Regulation Environmental Principles [33].

Following publication of the Joint Guidance the EA published Radioactive Substances Regulation (RSR): objective and principles document [34], which replaces [33].

The Joint Guidance [31] also states that the Government continues to develop a policy and regulatory framework that aims to ensure that:

- Radioactive wastes are not unnecessarily created;
- Such wastes as created are safely and appropriately managed and treated; and
- They are then safely disposed of at appropriate times and in appropriate ways.

A key part of the Joint Guidance describes the requirements for Radioactive Waste Management Cases (RWMCs). RWMCs [31] are highly relevant to interim storage since they include consideration of information required to substantiate the long-term safety and environmental performance of all radioactive waste streams on a licensed site. Store operators should actively maintain, utilise and review RWMCs during the period of storage.

The Joint Guidance encourages the application of decay storage management in the context of application of the waste hierarchy [31]. It also recommends effective characterisation of waste and segregation of short-lived waste streams, so that decay storage opportunities may be identified.

The Joint Guidance adds that if raw waste is stored, it 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 reasonably practicable to those for stored packaged wastes.

As well as applying the Joint Guidance appropriately, store operators will need to maintain a continuing dialogue with the safety, security and transport regulators, that is the ONR, the relevant environmental regulator (EA, the Scottish Environment Protection Agency (SEPA) or Natural Resources Wales (NRW)) and the local planning authority. In all cases it is recommended that the store operator should engage with regulators [31] from an early stage of planning storage systems to reduce the risk of non–compliance with the operator’s nuclear site licence or environmental permit and for consistency with developing cost-effective solutions - see GP1 (Stakeholder Engagement).

1.3.4 NWS Packaging Requirements

In England and Wales, before transport to a GDF, waste packages will need to meet the GDF’s Waste Acceptance Criteria (WAC). Until the WAC are established, the AoD process assesses packages against likely requirements, however because the WAC are not known the process carries risks that packages will not be disposable and may require rework. The assessment process is encouraged by the regulators (ONR and EA) whenever plans for the retrieval and treatment of ILW are developed or implemented. In Scotland, waste packages continue to be assessed through disposability assessment because the generic process is considered to also be a valuable risk management tool. SEPA and ONR currently advise that packages conditioned in anticipation of geological disposal are also suitable for long-term management in near-surface facilities, as required by government policy in Scotland [35].

Waste producers are encouraged to work collaboratively and maintain engagement with NWS throughout the development process of a packaging strategy (e.g. use of the NWS Expert View process). The Joint Guidance [31] states that early interaction and joint working between licensees and regulators is especially important at the strategy, options assessment and concept stages. It allows licensees to seek the regulators' views about:

- Improving safety and environmental protection;
- Reducing business risk and the potential for unnecessary expenditure by identifying, and if possible, resolving, any significant regulatory issues at this early stage; and
- Enabling the regulators to plan their resource commitments.

NWS, as the organisation responsible for delivering a GDF, has defined the package performance necessary to meet the transport and assumed disposability requirements of a GDF. The Waste Package Specification (WPS) documentation that details these requirements includes:

- The Disposal System Specification Part B – Technical Specification [36] for the high-level technical requirements defined by NWS to frame the development of a disposal system solution;

- Specification for Waste Packages Containing Low Heat Generating Waste Part C – Fundamental Requirements [37] for the envelope in which to develop waste packaging proposals that are compatible with the concept and generic safety case of a GDF; and

- Specification for Waste Packages Containing Low Heat Generating Waste Part D – Container Specific Requirements [38] for description of existing container designs that comply with the requirements of Part C.

NWS conducts an AoD process to ensure that waste packages are manufactured to be in compliance with GDF requirements, and that this performance is maintained through the lifetime of the waste package [39]. Following the AoD process, and utilising the supporting guidance, should greatly reduce the risk of packages requiring rework during interim storage as discussed in Section 5. Collaborative working in development of a packaging strategy is particularly important when involving interim products. NWS provides advice on appropriate levels of assessment and endorsement for the packaging of interim products. Guidance on the preparation of submissions for disposability assessments, a sub-process of AoD, for waste packaging proposals is given in [40].

Waste producers and store operators should maintain a continuing dialogue with the prospective disposal facility operator, especially when: establishing and updating store WAC, updating RWMCs, and developing store safety cases. Engagement between store operators and NWS should occur at an early stage of the development of the storage system and continue throughout the waste package lifecycle. This provides assurance of the future disposability of wastes and aims to resolve any emergent disposability issues - see GP1 (Stakeholder Engagement).

2. The Integrated Approach (Approach A0)

2.1 Overview

The Guidance comprises of several elements that collectively aim to achieve the objectives described in subsection 1.2.1. These elements are described below, and their inter-relationship depicted in Figure 1:

- **Principles (A to F),** which provide a consistent framework– see subsection 2.1.1;
- **Approaches (A0 to A30),** which are defined to be processes and methods to assist store operators select appropriate tools and/or take appropriate actions according to the context of their storage system. Approaches may also include the consideration of key attributes and factors which can be used to discriminate between different potential options to help select optimal solutions – see subsection 2.1.2;
- **Good Practices (GP1 to GP31)**, which highlight recommendations to store operators – see subsection 2.1.3; and
- **Toolkits (TK1 to TK24),** which comprise a collection of potential techniques, solutions or other options which have been derived from operational experience and R&D – see subsection 2.1.4;

Throughout the Guidance, common terminology is applied. It is recommended that the terminology concerning storage be used consistently by store operators - see the Glossary, listing Abbreviations and Acronyms and GP2 (Technical Terminology). Asset Management methodologies support consistent and effective application of the principles, approaches, tools, and techniques in a risk management context, and may be used to define mitigation activities (risk) and realisation actions (opportunities).

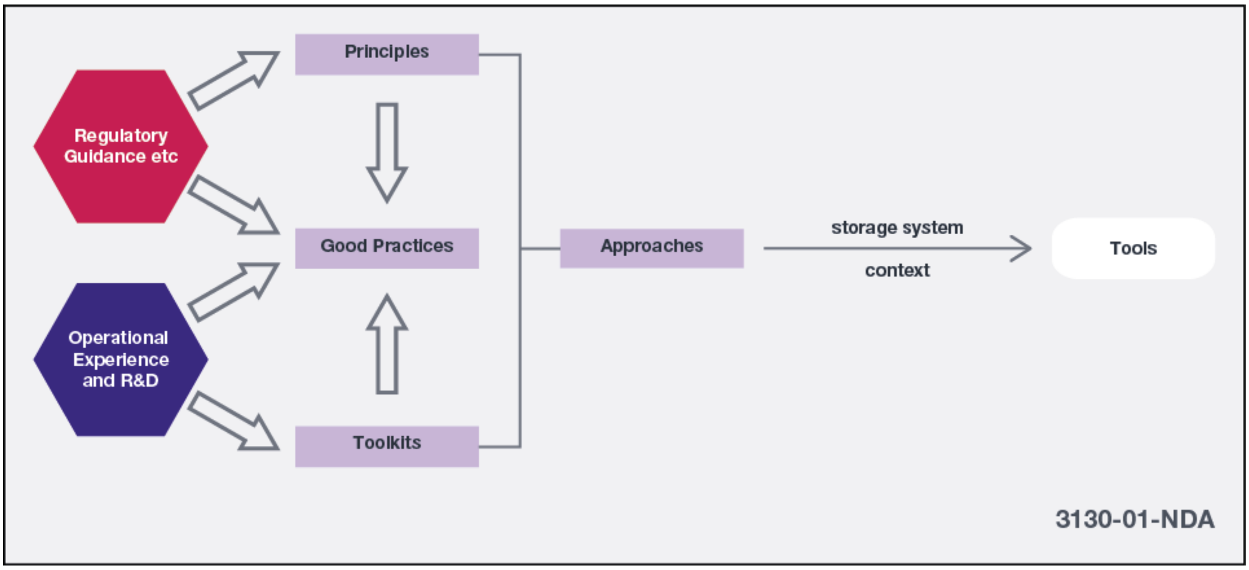

Figure 1 Guidance Elements and their inter–relationship.

2.1.1 Principles

The following seven principles, derived from stakeholder expectations, provide a framework for the Guidance:

i. **Cradle-to-grave lifecycle**. Packages should be designed and managed to maintain their performance as part of the lifecycle from manufacture of the container through to closure of a disposal facility. As interim storage is transitory, packages should be readily retrievable and exportable to finishing or rework facility (as required), a disposal facility or another store for continued storage;

ii. **Right Package ↔ Right Store.** Good package design should be matched by appropriate store designs, consistent with the storage, maintenance and security needs of the waste package. Due consideration of the hazards presented by the waste packages, the environment and quality of storage required to maintain package performance in addition to appropriate siting and assessment of external hazards. The overall storage system, i.e. the waste package, the store environment and the store structure, should have limited need for active safety systems, monitoring or prompt human intervention. Overall value for money through both avoiding over and under engineering should be demonstrated;

iii. **Minimising waste generation.** The waste hierarchy should be deployed across the system's lifecycle, from design through to decommissioning of the store to avoid unnecessary generation of waste while utilising resources sustainably;

iv. **Prevention is better than cure**. The storage system should be managed to minimise the risk that intervention will be required to maintain safety functions for both waste packages and the store. The storage system should be subject to regular and proportionate monitoring and inspection to demonstrate performance and enhance the understanding of how the system may evolve in the future;

v. **Foresight in design**. The storage system design should be flexible to meet likely future needs, taking into account uncertainties and incorporating proportionate contingencies. Designs should take account of the need for the store to be part of the UK-wide waste storage system;

vi. **Effective records management**. Records for both stores and packages should be managed appropriately and effectively throughout their respective lifecycle. Records required for retention should be identified and stored correctly. Consideration should be given to arrangements for changes in custodianship of records relating to both packages and stores; and

vii. **Knowledge management and sharing**. The experiences and lessons learned from existing store operations should be shared between store operators to inform development of store standards and designs. Learning from relevant overseas storage facilities should also be utilised effectively through collaboration. This collective information should be used to further inform development of UK storage standards and there should be emphasis on exploiting the insights and experiences gained, i.e. continual improvement. In the UK, the SOF is the primary knowledge exchange forum.

2.1.2 Approaches

To aid readability, the Guidance is presented in four main colour-coded sections:

a. **Waste package** performance requirements, management and design - Section 3;
b. **Store** performance requirements, environment, management and design - Section 4;
c. **Operation** of the storage system - Section 5; and
d. **Assurance** of the storage system - Section 6.

Overarching elements of the Guidance, relevant to all aspects of storage, are not colour coded.

Throughout the Guidance, 30 specific approaches are described and assigned a label, A*n*, with a further overarching approach, A0, being defined as the overall Integrated Approach (presented in Figure 2 and subsection 2.2 below). The 30 approaches are listed in Table 1 below:

Table 1 Approaches

A	Outline Description (subsection)	A	Outline Description (subsection)
1	Package Performance (2.4.1, 3.1, 4.4.2, 5.3.2, 6.3.1, 6.5.2)	16	Package Movements – Export (5.1.4)
2	Integrated Human Factors (2.4.2)	17	Package Emplacement (5.2)
3	Modifications to Existing Stores (2.4.3)	18	Maintaining Package Performance Functions (5.3)
4	Safe containerised storage pending future treatment (2.4.4)	19	Maintaining Environmental Conditions (5.4)
5	Sustainability (2.4.5)	20	Maintaining Store life-limiting Features (5.5)
6	Selecting Package Designs (3.2)	21	Extending Store Lifetimes (5.6)
7	Package Evolution and Assessment (3.3)	22	Baselining (6.1)
8	Lifetime Package Care and Management (3.4)	23	Monitoring and Inspection Techniques (6.2)
9	Development of Outline Store Design (4.1)	24	Monitoring and Inspection Rates (6.3)
10	Store Longevity (4.2)	25	Archiving (6.4)
11	Environmental Controls (4.3, 4.4)	26	Inactive Samples and Simulants (6.5)
12	Environmental Operational Limits and Conditions (4.4)	27	Auditing (6.6)
13	Package Movements - Import (5.1.1)	28	Knowledge Management (6.7)
14	Inactive Commissioning (5.1.2)	29	Human Resources (6.8)
15	Package Movements – Operations (5.1.3)	30	Records Management (6.9)

2.1.3 Good Practices

Throughout the Guidance, 31 headline recommendations to store operators are highlighted as good practices and assigned a specific label, GP*n*. The Good Practices are summarised in Section 7, and listed in Table 2 below with colour-coding as noted above. While the majority of the Good Practices are generic and applicable to all storage systems, additional notes are provided that describe any limits on their applicability, or attention is drawn to notable features.

Table 2 Good Practices

GP	Outline Description (subsection)	GP	Outline Description (subsection)
1	Stakeholder engagement (1.3.3, 1.3.4, 5.3)	17	Store design – environmental controls (4.3.1, 4.4.2)
2	Technical terminology (2.4)	18	Store design – contaminants (4.3 4.4.1, 4.4.2)
3	Technical competence (2.4.2, 3.1.1, 4.3)	19	Operational limits and conditions (3.3, 4.4.1)
4	Human factors (2.4.2)	20	Import contaminant checks (5.1.1)
5	Asset management (4.2, 5.3.1, 5.5)	21	Minimising movements - opportunities (5.1.3)
6	Research and development (2.3.1)	22	Package sentencing groups (5.3.3)
7	Peer groups (2.3.2)	23	Maintaining contingency space (5.3.3)
8	Package designs (3.2)	24	Maintaining intervention plans (5.3.3, 5.4)
9	Package materials (3.2, 6.5)	25	Access to rework facilities (5.3)
10	Maintaining transportability (5.1.3)	26	Extending store operational lives (5.5)
11	Package evolutionary processes (3.1.2)	27	Establishing system baselines (6.1)
12	Package care and management – controlled (3.4)	28	Recording system performance (6.2)
13	Package care and management - uncontrolled (3.4)	29	Monitoring and inspection rates (6.3)
14	Local planning constraints (4.1.2)	30	Maintaining an archive (6.4)
15	Store design - monitorability (4.1.3)	31	Deployment of dummy packages (6.5.1)
16	Store design – life-limiting components (4.2.2)		

2.1.4 Toolkits

Toolkits describing potential techniques or solutions derived from operational experience and R&D are referenced throughout the Guidance. The Toolkits are assigned in the text with a superscripted ‘^{TKn}’, are listed below in Table 3:

Table 3 Toolkits

TK	Outline Description (subsection)	TK	Outline Description (subsection)
1	Human factors (2.4.2)	14	Non-physical package intervention (5.3.3)
2	Sustainability (2.4.5)	15	Physical package intervention (5.3.3)

TK	Outline Description (subsection)	TK	Outline Description (subsection)
3	Basic container designs (3.2)	16	Environmental control changes (5.4)
4	Container materials (3.2)	17	Life-limiting component repairs (5.6)
5	Encapsulants (3.3.2)	18	Baselining (6.1)
6	Package evolution models (3.3.3)	19	Sample types (6.2)
7	Packaging innovations (3.5)	20	Package inspection and monitoring (6.2.1)
8	Outline store designs (4.1.1)	21	Environmental condition monitoring (6.2.2)
9	Store life-limiting features (4.2.2)	22	Monitoring life-limiting components - unshielded stores (6.2.3)
10	Temperature and relative humidity controls (4.3.3a)	23	Monitoring life-limiting components - shielded stores (6.2.3)
11	Moisture controls (4.3.3b)	24	Monitoring and Inspection rate models (6.3.1)
12	Contaminant controls (4.3.3c)		
13	Microbial and animal controls (4.3.3d)		

2.2 Roadmap

When the sections of the Guidance are integrated and applied in an iterative manner, as shown in Figure 2, the Integrated Approach (A0) may be used to help determine a suitable overall storage system. Alternatively, it may be applied to an existing storage system as a benchmarking exercise, or to optimise its operation or develop contingencies as part of risk management.

For planned stores, key factors which may discriminate between storage system designs are shown in Figure 2 - see also Section 3 and Section 4. However, as shown in Figure 3, the process is iterative with the store design and package design requiring compatibility. As such, pre-determining either a package or store design may yield a sub-optimal result, noting Principle B (Right Package ↔ Right Store). These 'key' discriminators, shown in Figure 3, are also used within many of the approaches to identify storage system specific tools.

It should be noted that the broad waste groups outlined in Figure 3 are taken from Reference [41]. These and the specific waste and packaging characteristics will have a major impact on the storage system design and underlines the importance of adequate characterisation to drive decision making [31]. Some SLCs may use different waste descriptions to the groups in Figure 3 but the key waste characteristics for storage will be the same.

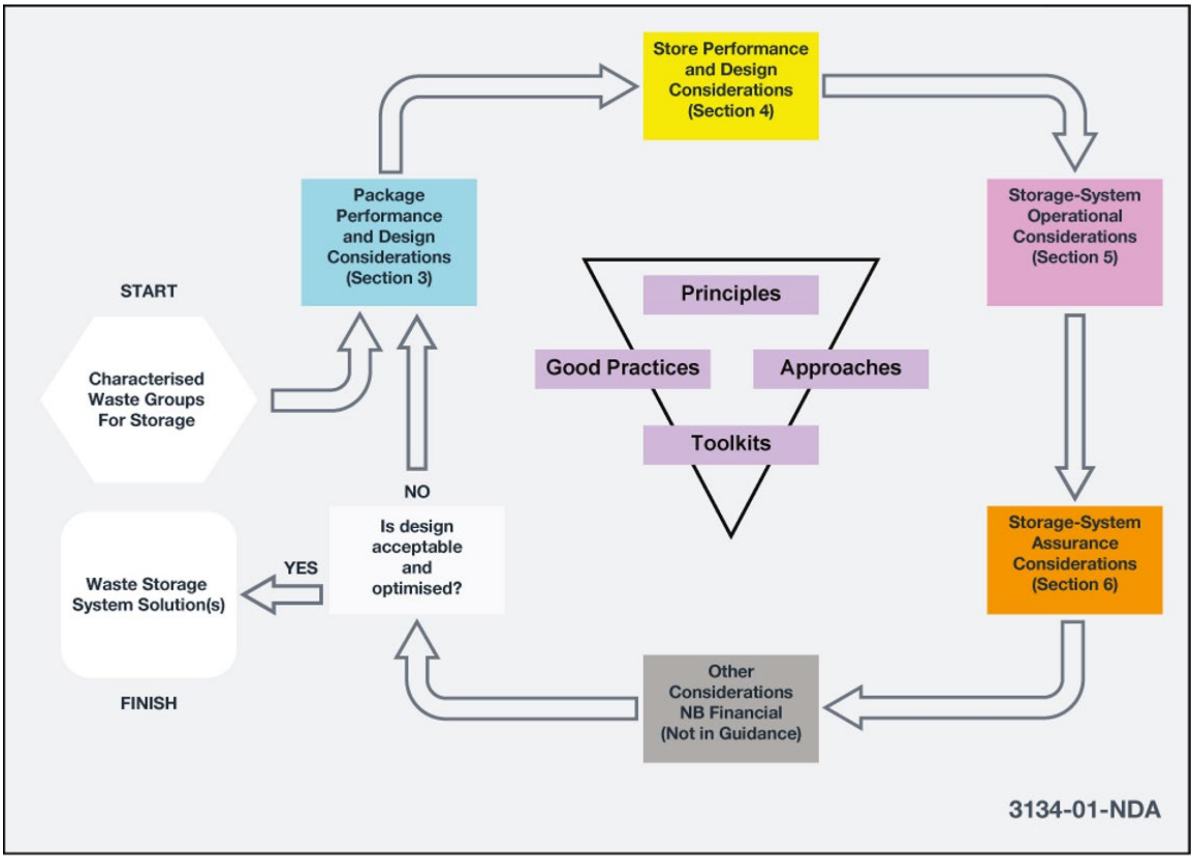

Figure 2 Schematic Representation of the Integrated Approach A0.

The Joint Guidance [31] outlines a categorisation approach that may be used to guide proportionality based on the safety and environmental challenges presented by the waste. Financial considerations are an important aspect of determining the design and operation of a storage system. While detailed consideration is outside the scope of the Guidance, a balance will be needed between the lifecycle costs of the storage system compared with the risk mitigated and the value of the asset managed. This will need to be agreed with appropriate stakeholders such as the NDA, Regulators and the relevant local planning authority.

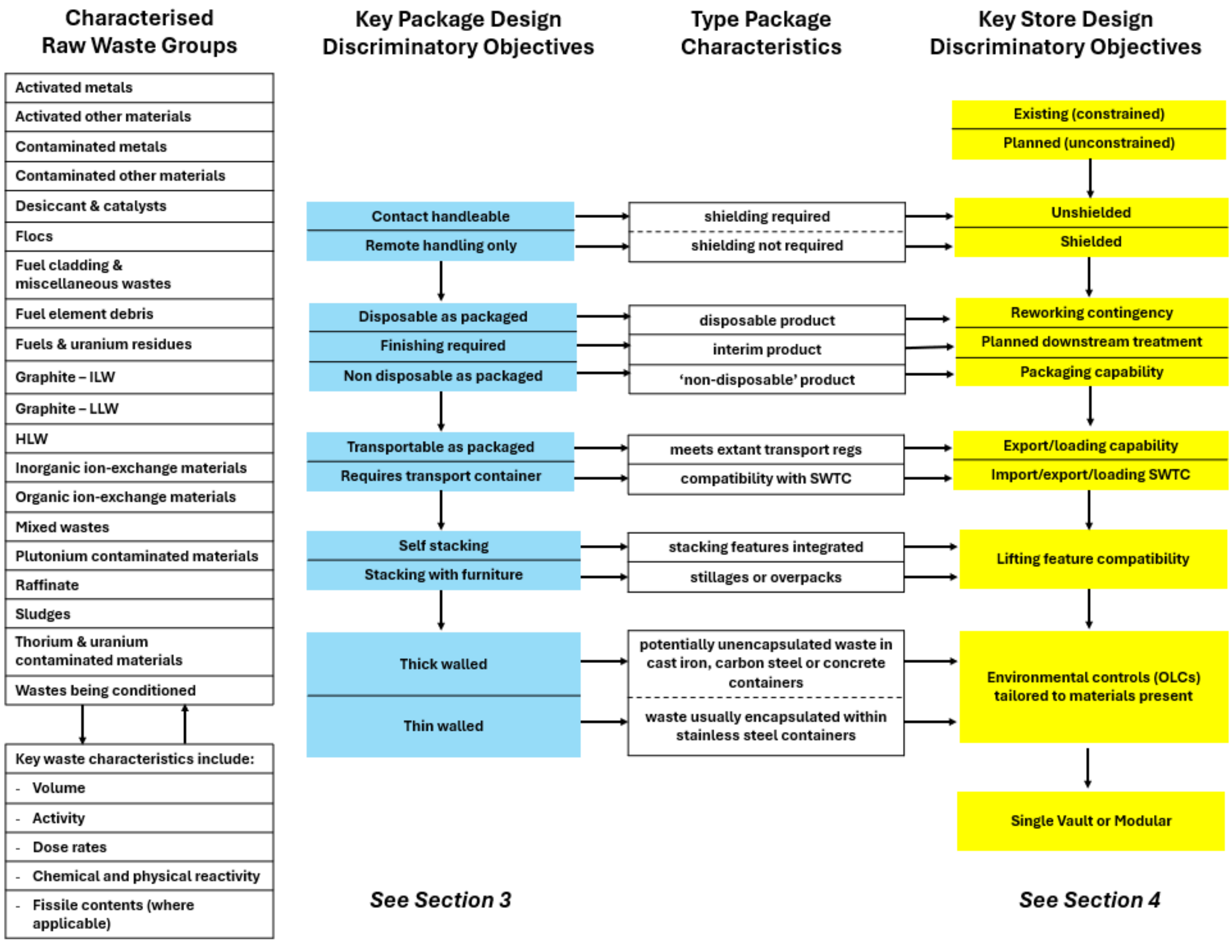

Figure 3 Key Storage System Design Discriminators and Characteristics.

2.3 Continuous Improvement

2.3.1 Research & Development

Users of this Guidance either seeking information on current or historic waste packaging and storage R&D or considering carrying out R&D should consult the NWDRF's Waste Packaging and Storage Working Group - see also GP6 (Research and Development).

SLC users are advised to contact their representative on the working group to co-ordinate any additional work and/or establish output from any pre-existing work. Other users should contact the group's chair. Representatives from ONR, EA, SEPA and NRW attend the Waste Packaging and Storage Working Group as observers.

2.3.2 Operational Learning from Experience

Store operators seeking information on UK-wide store operational experience are advised to contact the appropriate member of the NDA's SOF, or its chair, for more information - see also GP7 (Peer Groups).

2.3.3 Document Maintenance

The NDA Sponsor of the Guidance is the strategy manager, with implementation through the NDA Operating Companies. Additionally, three groups provide continuing oversight, these are the:

- Integrated Waste Management Theme Overview Group (IWMTOG) for waste strategy;
- NWDRF's Waste Packaging and Storage Working Group for R&D; and
- SOF for store operations and learning from experience. The SOF is now also recognised as the document curator.

Enquiries about future changes to the Guidance should be made through one of these groups, as appropriate, to represent any substantive requested changes to the NDA Sponsor. Comments may also be channelled through the email address provided in the Foreword.

2.4 Overarching Approaches A1 to A5

While most of the Approaches are outlined within specific subsections of the Guidance - see subsection 2.2 and Figure 2 - Approaches A1 to A5 are applied generically across the Guidance. These five generic Approaches are described below, and expanded as appropriate, in specific subsections. For example, Approach A1 is also discussed in detail in subsection 3.1.

2.4.1 Approach A1 - Package Performance

Approach A1 (Package Performance) is used widely within the Guidance. It describes package performance zones (see Figure 4 below) across the waste management lifecycle from packaging through to disposal. A1 [42] is integrated within many of the other approaches, e.g. see A16 (Package Movements – Export) on maintaining package safety functions as well as linking to NWS endorsement of waste packages for geological disposal.

The purpose of A1 is outlined below and shown figuratively in Figure 4; further details of its implementation are in subsection 3.1. A1 was established through workshops and engagement with the NWDRF. It can be utilised by store operators and waste producers as an aid to:

- Highlight package components which would benefit from being monitored and/or inspected throughout the lifecycle of the waste package. This may be achieved through probability and impact scoring;
- Derive appropriate store WAC/ Conditions for Acceptance (CfA) consistent with the facility's Environmental Safety Case;
- Target appropriate and effective R&D;
- Frame the importance of 'interim storage' as a component of the waste management cycle;
- Provide transparent and consistent 'yardsticks' for long–term package safety to stakeholders; and
- Define when intervention may be required to maintain safety functions.

Effective use of A1 (Package Performance) will require that the store operator has access to Suitably Qualified and Experienced Persons (SQEP) on the long-term performance of packages - see GP3 (Technical Competence). It will also require adequate baselining of waste package parameters, and of store parameters if the performance zone approach of Figure 4 is extended to store life-limiting components (see A20 (Store life-limiting Features) and A22 (Baselining)).

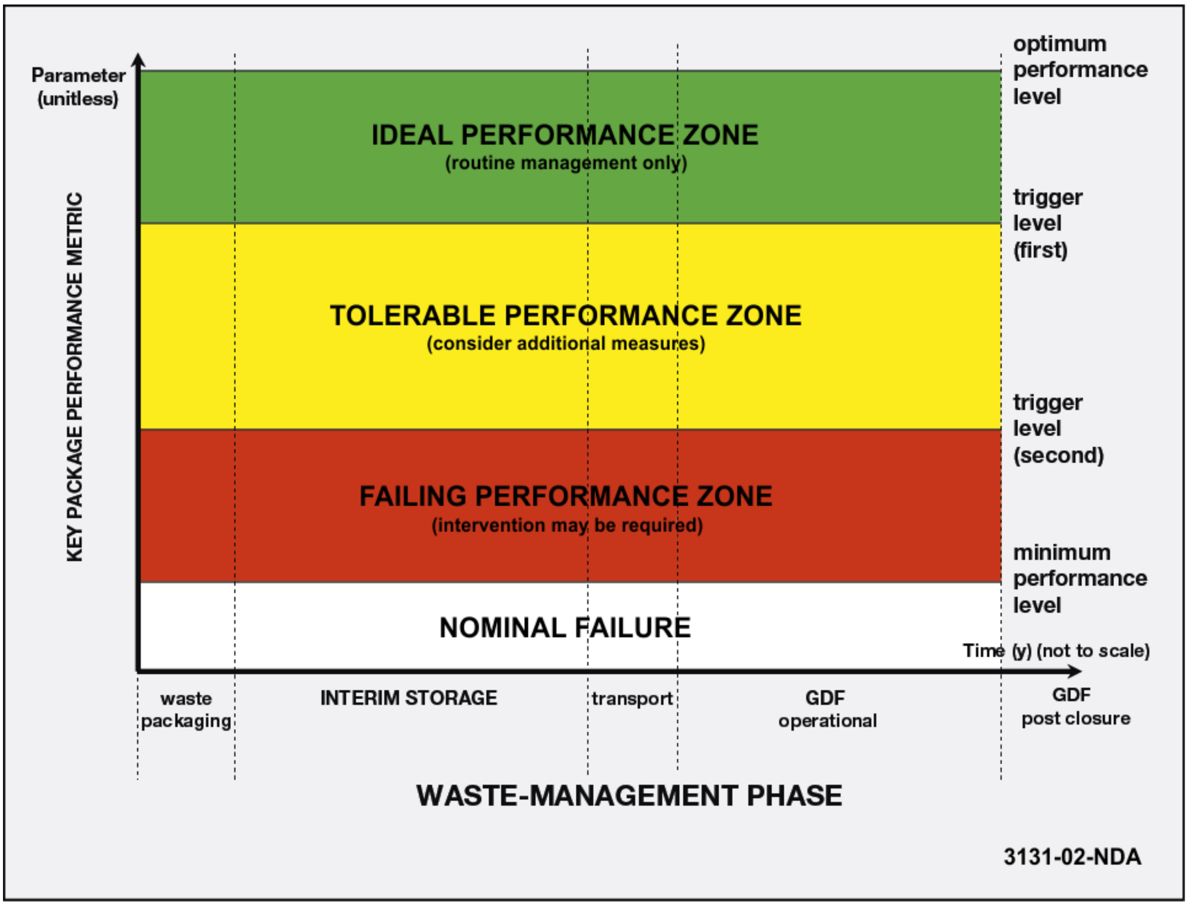

Figure 4 Basic Illustration of Approach A1 (Package Performance).

2.4.2 Approach A2 - Integrated Human Factors

Approach A2 (Integrated Human Factors) is taken from Reference [43], Human Factors Integration, which considers the design of the *Job* (including facilities, equipment and tasks); the capabilities of the *Person* required to perform tasks and interface with the system; and the features of the *Organisation* in which the system operates. Consideration of Human Factors (HF) should be widely applied across the lifecycle of the storage system, i.e. from design through to decommissioning. A more detailed description of this common three-pronged model of HF is given in the UK's Health and Safety Executive (HSE) publication HSG 48 [44].

The HF Approach should be instigated as early as possible in the storage system's lifecycle. By following A2 (Integrated Human Factors) and the identified toolkit - see HF2-HF15 in Reference [43][TK1] - appropriate tools may be selected to support the design, operation and assurance of the storage system according to the current stage of the lifecycle. Additional guidance on HF is provided on the Energy Institute website - see also GP4 (Human Factors) in Section 7.

2.4.3 Approach A3 - Modifications to Existing Stores

Approach A3 (Modifications to Existing Stores) may be used to determine how any gaps between current practice in an existing store and the guidance could be addressed. Much of the Guidance is based on the operational experiences of existing storage systems in the UK. This continues to develop over time and further good practices are identified. Additionally, R&D activities and new technologies continue to provide new and developed methods to determine how a storage system may evolve in the longer term. This approach is also applicable for remediation of faults which cannot be reconstituted in the storage system.

New stores should implement the good practices as identified by the Guidance and the SOF so far as reasonably practicable. For existing stores modifications should be identified using a gap analysis, as detailed below. Benefits and risks of modifications to store systems and operations should be identified and any decisions taken following the gap analysis should be appropriately justified.

Briefly, A3 (Modifications to Existing Stores) - see Figure 5 - consists of:

- Carrying out a gap analysis between relevant sections of the Guidance with the storage system, such as good practices and toolkits. Such a gap analysis might be prompted by regulatory review or inspection, or by the need to store a new package type;
- Assessing the significance of the gap, e.g. with respect to As Low As Reasonably Practicable (ALARP), BAT in England and Wales or BPM in Scotland, potential effect on disposability of waste packages and other optimisation considerations, commercial risks and any opportunities to manage the gap strategically, e.g. through inter-site 'store consolidation', informed, as appropriate, through stakeholder consultation;
- Justifying a decision to change a feature of an existing store, e.g. via a business case;
- Incorporating the decision through appropriate channels, e.g. modification to the safety case(s) affected, or updating the store risk register. Modifications which may affect the maintenance of disposability of waste packages may necessitate engagement with NWS; and
- Implementing and then periodically reviewing the decision.

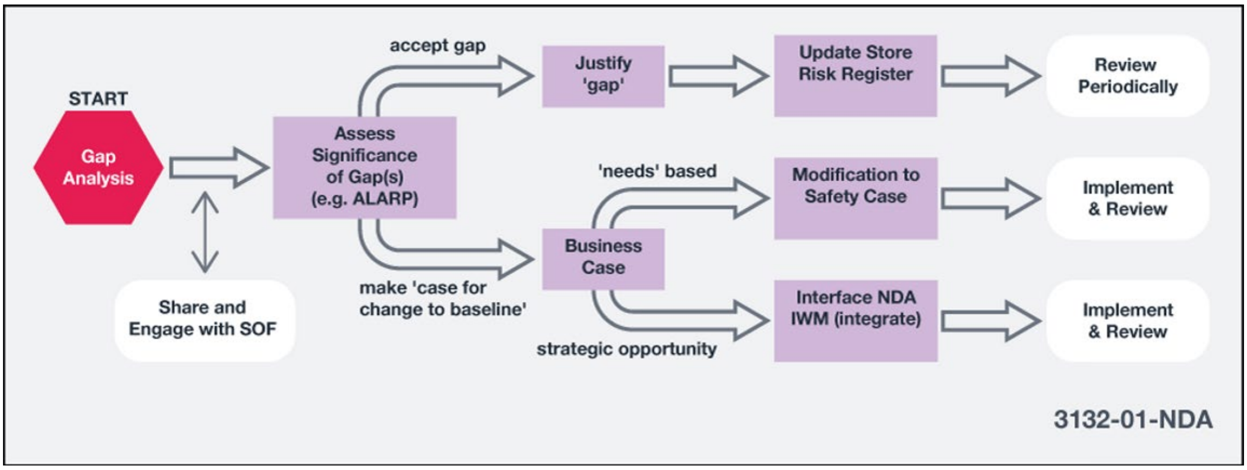

Figure 5 Simplified Flow–diagram of Approach A3 (Modifications to Existing Stores).

Throughout the staged approach, documented outputs could be shared with and informed by other store operators, e.g. via the SOF, with an objective to feedback outcomes into future issues of the Guidance - see subsection 2.3.

2.4.4 Approach A4 – Safe Containerised Storage Pending Future Treatment

There is a strategic and regulatory preference for disposable products to be produced at an early stage, however in some cases a multistage packaging approach may be adopted as opposed to single stage or immediate conditioning into a disposable waste product. This includes the storage of containerised unconditioned wastes which may require further treatment of packaging or wastes that are undergoing decay storage. Where a multistage packaging approach is proposed the long-term needs of disposability should be balanced against the short-term requirements of the Licensee in compliance with the Licence Conditions.

A multistage packaging strategy may be implemented for the following reasons:

- Operational benefits, including reduction of radiological risk associated with the current control of the waste and an enabling step for broad front decommissioning;
- Deferring implementation of finishing until more certainty is established on the future disposal system design and WACs, or to enable the technical maturity of a new processes to be further developed (e.g. thermal treatment);
- Reduction of technical risks and allowing action before finishing solutions are selected, developed and/or implemented; and
- Affordability.

Buffer storage in engineered stores

Buffer storage refers to the storage of wastes that are in a form that may not be directly disposable and may require the use of a finishing facility. There are two generic types of containerised wastes for buffer storage:

- The waste is in a disposal container, but may require dewatering, encapsulation, void filling and/or some other form of processing prior to disposal; and
- The liner or primary container holding the waste is expected to be placed into a disposal container and the waste may require some form of processing, which may include dewatering, compaction, encapsulation or vitrification.

In the considerations for buffer storage, the following are particularly relevant for store operators:

- Consider the impact on store safety cases;
- Consider the placement and arrangement of waste packages that are being stored to take advantage of radioactive decay; and
- Consider the requirements for eventual export of waste packages, including the need to preserve inventory information and other data needed for eventual waste acceptance at other facilities, such as the Low-Level Waste Repository (LLWR). The availability and capabilities of future treatment and disposal facilities should be monitored, as facility availability may be less certain in the future.

These factors are considered in more detail in later sections of this document.

Adoption of these approaches will require justification with the UK regulators and clear demonstration of ALARP and BAT/BPM [11]. They may place additional requirements on store operators for additional operational controls and planning practices. The principles, approaches, good practices and toolkits described in this document, including those associated with environmental conditions, are as applicable to interim products as they are to disposable products. Where necessary, further guidance on the storage of interim products is given within specific sections, with particular consideration on requirements established within sections on characterisation, condition monitoring and inspection, learning plans, knowledge management and selecting package designs.

Decay storage

Decay storage is recognised in the NDA Integrated Waste Management strategy [11] to be suitable for wastes typically comprising radionuclides with a relatively short half-life (approximately 30 years or less). This waste management approach is consistent with existing NDA strategy and regulatory guidance, for example, concerning application of the waste management hierarchy, and it supports an NDA Strategy commitment [10].

Adopting a strategy of decay storage management for radioactive waste can be part of an ALARP, BAT/BPM or other optimisation case, as an enabling step that increases the range of potential treatment options and end points for a given waste stream (e.g. disposal at near surface facility, Very Low-Level Waste (VLLW) or reuse).

2.4.5 Approach A5 – Sustainability

The NDA has established strategies and frameworks where sustainability is incorporated throughout each strategic theme. Sustainability considerations for the modification of existing waste stores and/or new waste stores shall demonstrate alignment with the following documents:

- NDA Strategy [10] - Sustainability is incorporated throughout each strategic theme of the strategy, supporting the UK's net zero commitments by reducing emissions, applying circular economy principles, and enabling land reuse;
- NDA Sustainability Strategy [45] - The sustainability strategy is centred around four legacies; Decommissioning, Environment, Socio-economic and Cultural and encourages whole-lifecycle thinking, proportionate application and intergenerational equity;
- NDA Value Framework [46] - Incorporates sustainability and social value within the 3 pillars; environmental, economic and social factors all of which overlap with the NDA values, as shown in Figure 6. The framework ensures sustainability measures deliver demonstrable whole-life value and are not pursued in isolation; and
- NDA Sustainability in Business Cases [47] – Provides guidance for key sustainability considerations for strategic, economic and commercial aspects of business cases and includes templates for assessment and assurance.

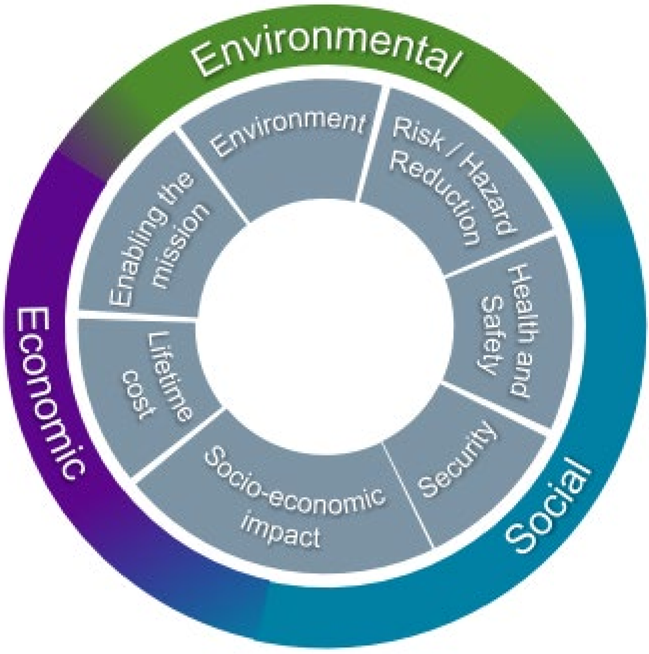

Figure 6 NDA Value Framework and the three pillars of sustainability and social value.

The NDA are committed to delivering the mission in alignment with the United Nations 17 Sustainable Development Goals. The strategies and frameworks outlined above provide examples of how the NDA Group can contribute to achieving these goals.

A report about the optimisation of future waste stores was produced by the NDA in 2024 [48], which identifies opportunities for improving the delivery of stores and maximising the value that they provide for the NDA and for society. From this, a set of sustainability 'guiding principles' for stores have been established, which cover the whole lifecycle of both waste packages and stores ([TK2]).

In addition, recognised sustainability assessment tools may be used to support good practice. The Building Research Establishment Environmental Assessment Method (BREEAM) may be considered as a reference framework to support sustainable design and construction of radioactive waste stores. BREEAM technical manuals are available for both new construction [49] and refurbishment [50]. Its use should be selective and proportionate with a focus on credits that deliver whole-life value such as energy efficiency, materials, waste minimisation and climate resilience. BREEAM shall inform good practice and decision making but shall not be treated as a mandatory compliance target.

3. Package Performance and Design

This section comprises six examples of good practice, three approaches and five toolkits to promote robust package performance and design. It includes guidance on:

- Current standard container and package designs and materials
- Emerging innovations which may affect future interim storage requirements
- How to establish a credible baseline for new designs and materials
- Generic and specific package safety functions
- Relating safety functions to performance criteria
- The latest understanding on package evolutionary processes
- Good package care practices before import into a store (both between manufacture and use, and before store import)

Interim storage is a key stage in the lifecycle of a waste package, as shown in Figure 7. Package designs should be selected and waste packages managed to ensure that the package performance will meet requirements for disposal following a period of interim storage. Waste conditioning and packaging operations must also be compliant with the relevant Licence Conditions and demonstrate that risks and doses to workers are ALARP.

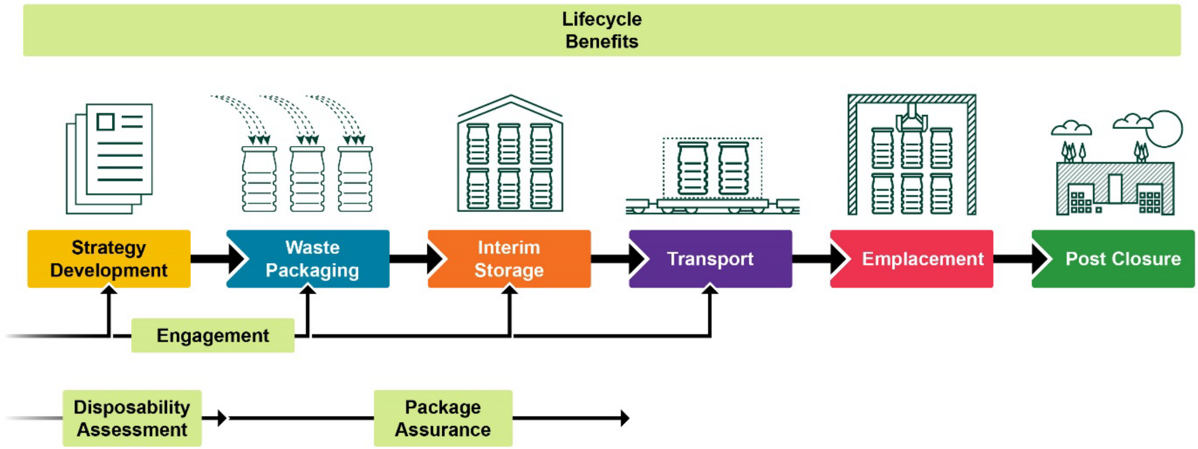

Figure 7 An illustration of the lifecycle of a waste package for disposal at a GDF and relationship to the AoD process.

Unless there are compelling reasons, packages should be designed to be *capable* of being disposable without the need for additional packaging steps before export. However, there may be exceptions, including:

- The required use of a transport container at export to meet transport regulations;
- Waste placed in final disposal containers with plans for further treatment (e.g. encapsulation) prior to disposal, where finishing facilities are not available at the time of packaging or the need for finishing has not yet been confirmed. This may include contingencies in the package design which may accommodate significant evolution, such as expansion, that otherwise may have led to an unacceptable risk of rework; and,

- Packages for which a period of storage is intended (e.g. where a decay storage management approach is to be followed) or where a period of storage is required for the packages to meet certain transport criteria (see subsection 3.2).

3.1 Approach A1 - Package Performance

3.1.1 Overview

A1 (Package Performance) [42] - see subsection 2.1.2a - consists of the following steps:

- Defining the stages of the relevant lifecycle, e.g. see *x*–axis in Figure 8;
- Identifying waste package 'groups' likely to evolve in similar ways within the store – see Figure 3;
- Identifying the package safety functions over the lifecycle for each identified waste package group - see subsection 3.1.2;
- Identifying evolutionary processes that may affect the performance of the safety functions and measurable indicators of these processes – see subsection 3.1.3; and
- Calibrating the indicators, where practicable, to provide indicative package performance zones in order to guide appropriate actions in response to any measured or inferred evolution - see subsection 3.1.4.

A1 (Package Performance) should be applied proportionately based on the risk arising from the package and to its future disposability and quantified to the extent of available data to underpin the performance zones and SQEP judgment applied as necessary - see GP3 (Technical Competence). A worked example of A1, applied to identification markings, is provided in Reference [51].

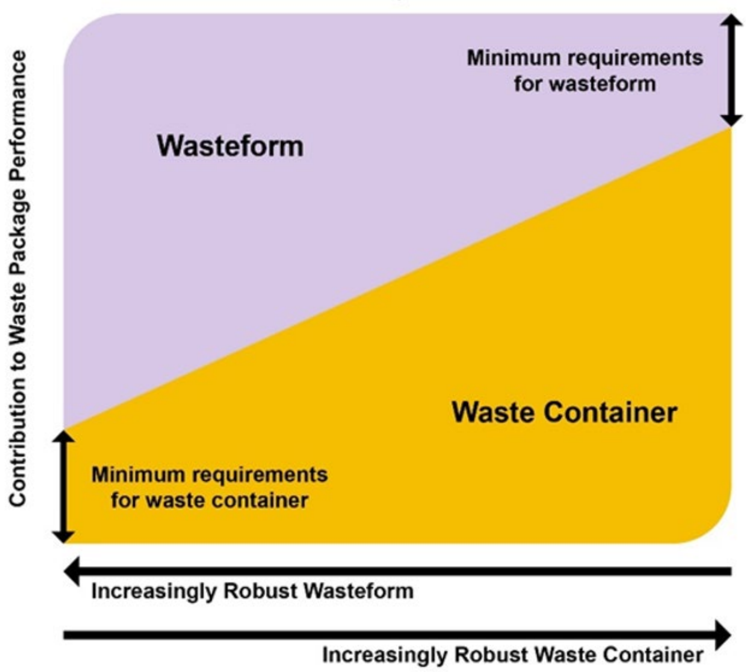

Figure 8 Illustration of the relative contribution of the waste container and the wasteform to the performance of a waste package.

3.1.2 Storage Functional Performance Requirements

The following functional performance requirements have been defined for waste packages during interim storage [36, 42]. These overlap with the safety functions for waste packages identified for the operational phase of a GDF [37]:

a. **Containment during normal operating conditions** of the radioactive inventory with minimal and predictable release of content;
b. **Containment under accident conditions** arising from:
    i. **impact events** with minimal and predictable release of hazardous content during impact of relevant magnitude;
    ii. **fire** with minimal and predictable release of hazardous content during fire of relevant magnitude.
c. **Identification** by unique markings and these must relate to accessible package records [52];
d. **Handling**, including retrievability, by use of designed lifting features.
e. **Stacking:** once emplaced can withstand stacking stresses and remain in position;
f. **No over–pressurisation** through effective dispersion of any gases through filters/vents;
g. **Shielding** to provide adequate radiation shielding for the store safety case and/or transport; and
h. **Criticality safety** by preservation of a safe maximum content and distribution of fissile material within a package and with neighbouring packages.

The relative significance of the safety functions will vary between packages depending on its characteristics. Some safety functions will always be highly relevant, including containment, identification and handling, consideration should also be given to the impact of expansive processes on the retrievability of waste packages within an interim store. Some safety functions may require specific consideration for interim products, particularly if they contain water and reactive components. Within a particular store the requirement for stackability might be relaxed, but appropriate consideration will still be necessary with respect to future store or disposal facility requirements.

Not all the safety functions will be relevant to all waste package groups. The potential for over-pressurisation will be waste package specific, and most likely relevant to packages with reactive metals, and degradable organics. Shielding requirements will be package-dependent. Similarly, criticality will be highly waste package specific, with only stores with fissile inventory of potential concern. The distribution of such packages and interaction with moderating materials will, however, be an important consideration.

One method to identify prioritised safety functions is Failure Modes and Effects Analysis (FMEA), which is a procedure in operations management for analysis of potential failure modes within a system for classification by severity or determination of the effect of failures on the system [42] - see GP11 (Package Evolutionary Processes).

Table 4 Example safety functions, evolutionary processes and potential indicators.

Storage safety function (main component delivering function)	Example evolutionary processes	Potential indicators
Containment - normal operations (wasteform and container)	(i) wasteform expansion (ii) container corrosion	(i) package expansion, internal strain, gas generation (ii) direct measurement of corrosion or salt deposition as risk factor
Containment - impact accident (wasteform and container)	(i) wasteform expansion, cracking, fragmentation, embrittlement (ii) container corrosion	(i) package expansion/deformation, internal strains and properties, gas generation (ii) direct measurement of corrosion or salt deposition as risk factor
Containment - fire accident (wasteform and container)	(i) wasteform physico-chemical properties (ii) container corrosion	(i) internal properties (ii) direct measurement of corrosion or salt deposition as risk factor
Identification (container and records)	(i) container corrosion (ii) loss of records	(i) direct measurement of readability, corrosion or salt deposition as risk factor (ii) quality assurance audits
Handling (container)	(i) container corrosion (vicinity of lifting features)	(i) direct measurement of corrosion or salt deposition as risk factor in vicinity of lifting features
Stacking (wasteform and container)	(i) wasteform expansion (ii) container corrosion	(i) package expansion, deformation, internal strain, strength, gas generation (ii) direct measurement of corrosion or salt deposition as risk factor

Storage safety function (main component delivering function)	Example evolutionary processes	Potential indicators
Prevent over-pressurisation (wasteform and container)	(i) wasteform physico-chemical properties (ii) container corrosion / properties filtered vent	(i) internal properties (ii) direct measurement of corrosion or filter performance, gas generation
Shielding (provided by wasteform and container)	(i) wasteform physico-chemical properties (ii) container corrosion	(i/ii) dose rates
Prevent criticality (provided by wasteform)	(i) wasteform physico-chemical properties / distribution of fissile material	(i) internal properties

3.1.3 Evolutionary Processes and Indicators

Waste packages, and hence their properties and performance, may evolve during interim storage at variable rates. However, safety function performance and disposability must be suitably maintained over the full package lifecycle, and it would not be acceptable to target 'just safe' performance at the point of package export from the store. It is noted that the expectations and requirements for Conditioning Monitoring and Inspection (CM&I) may differ between fully conditioned waste packages and those containerised for storage pending future treatment, due to the differences in the nature of their evolution.

The evolutionary processes, which may affect the safety functions, and their measurable indicators should be identified and documented by waste producers and store operators and used to develop an effective monitoring and inspection approach (see subsection 6.2). Where possible preventative measures should be implemented to remove or limit the impact of identified evolutionary processes.

Table 4 outlines example evolutionary processes which could affect the safety functions and suggests indicators of the degradation processes which could, in principle, be measured. An overview of evolutionary processes is provided in subsection 3.3 and Reference [53]. Further R&D is typically coordinated through the NWDRF.

3.1.4 Performance Zones

For each safety function - see also Reference [36] - the performance defined by relevant measurable indicators should be assigned to one of three performance zones, as illustrated in Figure 4:

- **Ideal** where any evolution has no negative bearing on the safety performance. Initially, a waste package that has been produced in conformance with plant processing parameters should have ideal performance in all relevant functions;
- **Tolerable** where evolution has led to detectable change, but resulting in an acceptable reduction in performance; and
- **Failing** where evolution has led to a significant loss in performance, but a 'margin of safety' is retained.

'Measurements' of the indicator(s) of the safety function, rather than the safety function itself, should be presented on the *y*–axis.

The performance zones in the Guidance are represented as being constant throughout and between phases. However, this is a simplification. For example, during transport, IAEA prescribed requirements [13] may be provided to a significant extent by a transport container such as the Standard Waste Transport Container (SWTC).

For each safety function the indicators of performance should be calibrated - see subsections 5.3 and 5.4 - to describe:

- **Optimum** performance, which defines the target specification;
- **First trigger level**, which defines the transition from ideal to tolerable performance. It acts as a 'flag' that the package may require additional management intervention to maintain safety functions;
- **Second trigger level**, which defines the transition from tolerable to failing performance. It acts as a 'flag' that the package may require physical intervention, i.e. reworking, to maintain safety functions; and
- **Minimum** performance, which defines the lowest performance at which the safety function is still provided. Performance below this can be considered as nominal package failure, and reworking will be required to restore the safety function(s).

If there is any doubt about the safe performance of the waste package during packaging operations and import into the store, or any other stage of the lifecycle, the store operator should establish a package sentencing group to advise on appropriate actions to take - see subsection 5.3.

3.2 Approach A6 – Selecting Package Designs

Waste packages used for LLW/ILW destined for the GDF (excluding DNLEU) are grouped into three types: 'unshielded', 'shielded' and 'robust shielded'. NWS has identified a range of standardised designs of waste containers for packaging LLW/ILW destined for the GDF [54]; NWS Packaging Specifications and Guidance Notes[TK6]. It is recommended that store operators base their waste system storage designs around these standard designs unless there are compelling reasons to adopt different package or store designs - see GP8 (Package Designs).

NWS provide guidance on how to meet the waste container design requirements for standardised waste containers [55]. The guidance covers the following aspects:

- External dimensions;
- Stackability;
- Identification;
- Handling features;

- Sealing;
- Venting;
- Waste loading; and
- Container materials.

Material property considerations important to the container design and materials previously endorsed for standardised waste containers are detailed in NWS guidance [55]. These materials broadly include:

- Stainless steel;
- Reinforced concrete; and
- Ductile cast iron.

Materials chosen in the package design must be shown to be sufficiently robust for the intended lifecycle [31]. The container design and materials chosen should ensure the potential for adequate package performance - see Figure 8 in subsection 3.1. Emerging innovations which may enhance the packaging toolkit may also be considered - see subsection 3.5. Samples of container materials may be incorporated into a monitoring programme as described in subsection 6.5 - see GP9 (Package Materials). Store operators should ensure that the waste containers selected are consistent with the design of the store, and vice versa. Additional consideration will also be required for wastes that are not in a disposable form during interim storage.

3.2.1 Containment Functionality

The design of the package for disposal in the GDF requires consideration of the relative contribution from the container and wasteform to the overall barrier [53] afforded from the waste package as shown in Figure 8.

In the UK, cementitious materials are the most widely used encapsulants to immobilise radioactive waste. The cementitious materials most commonly used are hydraulic blends of Ordinary Portland Cement (OPC) and either Ground Granulated Blast Furnace Slag (GGBFS) or Pulverised Fuel Ash (PFA). Additional materials[TK4], including polymers such as two-part epoxy resins, may be considered as part of an encapsulation toolkit.

In specific cases (interim products), immobilisation of the waste in cementitious or other encapsulants may be planned (or may be considered a contingency) some period into interim storage or only just before transport to the GDF. In these cases, in order to retain predictable and acceptable evolution during storage, the functionality of the container and any additional internal barrier (e.g. inner liners) becomes particularly important.

3.3 Approach A7 - Package Evolution and Assessment

Approach A7 (Package Evolution and Assessment) considers that after manufacture, the waste package will evolve during the interim storage, transport, operational and post-closure phases. The design of the waste package must ensure that the package performance requirements continue to be met during all these phases. Awareness of typical evolution mechanisms should be maintained during the interim storage period. These include:

- Microbial degradation;

- Corrosion;
- Radiation-induced degradation;
- Gas generation;
- Physical degradation;
- Voidage;
- Mass transport; and
- Release of pollutants.

Further details on the mitigation of these evolution mechanisms are given in Reference [56]. It should be noted that there is uncertainty for the processes and rates of degradation, particularly for new materials, which may need to be managed. Approach A7 (Package Evolution and Assessment) consists of the following steps, many of which may be iterative steps when the applied to storage systems being planned:

a. Characterising the waste, especially with respect to chemical and physical reactivity after packaging;
b. Defining container, shielding materials and, even when encapsulation may be planned after storage (i.e. interim products), encapsulants as appropriate;
c. Identifying the environmental conditions to be provided by the storage system;
d. Identifying the wasteform-container and container–environment interactions by appropriate SQEP and engagement through the disposability assessment process, including consideration of:
    - External and internal corrosion - see also subsection 3.3.1 - which should also provide relevant background to the setting of Environmental Operational Limits and Conditions (OLCs) (Approach A12) and the development of Environmental Controls (Approach A11);
    - Wasteform evolution processes including expansion factors - see subsection 3.3.2; and
    - Long–term package evolution - see subsection 3.3.3.
    - Assessing the implications from evolution - see Figure 4; and
    - Feeding back the findings, as appropriate, to the storage system design - see Section 4.

A more thorough overview of processes relevant to the evolution of waste packages is provided in the Reference [53]. Indicators of package evolution are discussed in subsection 3.1.3.

3.3.1 Container Corrosion

The main factors affecting the external and internal corrosion of the waste container - see Reference [53] - during interim storage, include the:

- Type of container and material used: if a metallic container is used, the type of metal and its metallurgical and mechanical history; if a concrete container is used, the nature of the metal used for the rebars and the thickness and quality of the concrete surrounding them; where coatings such as paint or galvanisation are used the potential maintenance requirements should be considered;
- Environmental conditions of the store e.g. temperature and presence of liquid water or ionic species in solution in contact with the surface, notably in crevices;
- Presence of nutrients able to sustain microbial growth; and
- Radiation dose rates.

The forms of corrosion [53, 57, 58, 59, 60, 61] most relevant to interim storage are:

- **General corrosion.** Stainless steel most commonly used in the UK as the container material, i.e. 304L and 316L, is highly corrosion resistant under normal operating conditions [57]. Duplex grades [58] are expected to be at least as corrosion-resistant. Unprotected carbon steel and cast iron surfaces are more susceptible [59]. For concrete containers, general corrosion of the rebars upon carbonation and exposure to chloride is expected to be a relevant degradation mechanism;
- **Localised corrosion and stress corrosion.** Specific forms of localised corrosion include crevice and pitting corrosion. In areas of mechanical stresses localised corrosion may lead to the development of Stress Corrosion Cracking (SCC) [57]. The resistance to corrosion of packaging materials and active controls to prevent the initiation and propagation of localised corrosion and SCC should be considered. Localised corrosion can also occur in concrete containers in the presence of high chloride concentrations; and
- **Other forms of corrosion.** These include Microbiologically Influenced Corrosion (MIC), galvanic corrosion, radiation assisted corrosion and corrosion at welds. Current container materials, under normal operating conditions, may require consideration of these processes on a case-by-case basis, but quality controls and good engineering practices should adequately control these processes [53].

Much work has been carried out through the NWS research programme to define operational limits under realistic storage conditions [60, 61]. This is discussed further in subsection 4.4 Approach A12 - Environmental Operational Limits and Conditions.

3.3.2 Wasteform Evolution

Assuming appropriate quality control and monitoring and inspection during interim storage, it is expected that wasteforms will be robust so as to ensure containment and safe handling over interim storage timescales. The following processes are considered notable - see also Reference [62] - as potentially affecting package performance during interim storage. The store operator should consider them when defining store WAC, OLCs and package emplacement - see subsection 5.2:

- **Corrosion of reactive metals,** which has the potential for expansive chemical reaction and generation of hydrogen gas. Where practicable this reactivity should be removed before packaging, however, temperature is also a factor in corrosion. Consideration should also be given to including sufficient voidage to accommodate expansion caused by corrosion. Experimental work which has demonstrated that mechanical ‘shocks’ to packages [63] may disturb protective corrosion products leading to short-term enhanced corrosion rates until the corrosion layer reforms. Material may be generated from corrosion that is more susceptible to release in accidents, which may change the nature of the hazard;
- **Internal reactions with encapsulants**, where these may lead to gross dimensional change (swelling or shrinkage) of the wasteform. Good encapsulant formulation and measures to contain expansion such as sacrificial voidage or engineered voidage, such as bins, should reduce the risk;
- **Radiolysis** of sensitive organic materials, which may break down into reactive species;
- **Carbonation** of cementitious encapsulants and concrete containers [53], which will change the wasteform properties, such as gas permeability and pH buffering capacity, over time; and

- **Microbial action**, in wasteforms where the pH is not uniformly high and in the presence of microbial nutrients, may result in gas generation and formation of reactive species. Microbial action may be particularly important in the case of wet, non-encapsulated wastes. Reduced temperatures and low moisture levels may control microbial activity, this may be achieved using drying equipment.

3.3.3 Evaluation of Package Evolution Toolkit

The following comprises a toolkit[TK5] of models which may establish package evolution:

- **Gas generation,** store operators should consider use one of the existing standard tools to predict gas generation arising from the three most relevant processes: metal corrosion, microbial degradation of organic materials, and radiolysis. For example, the Magnox Gas Generation model (MAGGAS) [64], which was endorsed by the NWDRF for its industry-wide suitability in 2009. A dataset of corrosion rates for grouted wastes, based on extensive experimental research and measurements over the last few decades, is provided in Reference [65]. Data for non-grouted conditions are also broadly available in the technical literature, although they may have not been consolidated in a specific source. Other suitable models are also available.
    - Such models are also valuable in helping to determine suitable ventilation rates when applied with Computational Fluid Dynamics (CFD) techniques - see subsection 4.3.3. In principle, the models could also be used as a diagnosis tool to help identify any unusual patterns of gas generation or explore emplacement approaches to inform underpinned future management practices - see subsection 5.2.
- **Wasteform expansion,** NWS has developed specific modelling calculations [66] to estimate the effect of wasteform expansion caused by the formation of corrosion products. Depending on the strength of the wasteform, and container design, it has been estimated that 10-25% volume expansion could be accommodated by thin-walled stainless steel containers before rupture. However, other safety functions, such as handling and stackability, may be affected before this point and these tools should be utilised to frame package performance considerations; and
- **Corrosion,** NWS is developing a prototype model to predict localised corrosion and SCC of stainless steel containers during interim storage and the operational period of a GDF [67]. The model is currently being expanded to refine the treatment of stainless steel corrosion but also to include the degradation of epoxy-resin coated Ductile Cast Iron Containers (DCICs). It is recommended that store operators maintain a watching brief on its development, as the model has the potential to be a useful tool for existing and planned stores with stainless steel containers.

3.4 Approach A8 - Lifetime Package Care and Management

A good package care approach is outlined in a report [68] and provides a framework for Approach A8 (Lifetime Package Care and Management). A7 is based on the premise that effective waste package and container care should start well before import into a store - see GP12 (Package Care and Management – Controlled) and GP13 (Package Care and Management – Uncontrolled). While originally developed to focus on austenitic stainless steel containers, A8 is applicable more widely. Key stages of package care which should be considered by store operators are:

- Cross-site transfer of package to the store;
- Emplacement in the store;
- Monitoring and inspection within the store; and
- Export of package from the store.

The following practices are highlighted:

- Waste containers should remain wrapped wherever possible using non-halogenated plastics. Containers should be kept dry, away from corrosive chemicals and protected from contamination by chlorides, grease, dirt and dust. If any material is deposited on the container, it should be removed as soon possible to avoid the potential for corrosion;
- Target waste package surface chloride concentration should be well below the maximum values considered in the store's environmental control - see subsection 4.3. If the surface chloride level is above the target level cleaning will be necessary using chloride-free detergent solutions, followed by a demineralised water wash, until the required degree of surface cleanliness has been achieved. The containers should then be thoroughly dried and promptly sealed in a suitable non-halogenated plastic covering. A chloride-free desiccant in the space between the waste container and the plastic covering should be used;
- Lifting and handling of stainless steel containers should, where practicable, use equipment made from corrosion-resistant materials especially where these may contact the package directly. Ferrous particles from carbon steel tools or handling equipment can become embedded in the container surface and suffer corrosion. The presence of corroding ferrous material may initiate corrosion of the underlying stainless steel and make it more difficult to assess whether corrosion of the stainless steel itself might be occurring;
- Lifting and handling procedures for containers should minimise the potential for scratches and damage of any corrosion protection system which may be applied;
- The use of adhesive films on the container surface, such as packaging tapes and labels, should be avoided, since this may leave residue which is difficult to remove and lead to contamination with organic material which may favour the development of microbes; and
- During transport and on–site transfers precautions should be taken to protect the packages from physical damage, windblown contamination and salt contamination from external sources. Weather-proof covers should be used, and, where practical, engineered into the design of buildings, to aid fitting; this protects packages from salt, weather and guano.

3.4.1 Records Management

A key aspect of demonstration of package performance, particularly with reference to disposability, is records management. Further information and NWS requirements are given in subsection 6.9.

3.5 Innovations Toolkit

The following waste package initiatives[TK7] are noted as potentially influencing future storage systems. Store operators planning new stores should consider the current status of these to inform decision making:

a. **Management**

   I. Improved implementation of the waste hierarchy principle, with segregation of components for reuse, recycle and prompt disposal as Lower Activity Waste (LAW);

   II. Diversion to a near-surface disposal facility which could reduce the volume for interim storage or the time necessary to maintain packages in interim storage, if a disposal facility was available in the near term;

   III. Decay storage management opportunities are captured within A4; and

   IV. Similarly, generation of interim products, where there is a driver to do so and a BAT/BPM / ALARP case has been made, are also detailed within A4.

b. **Processing**

   I. Including thermal treatment and dissolution. Both processes which could reduce the chemical reactivity and volume of wastes but might result in packages with higher specific activities and shielding requirements.

c. **Encapsulants**

   I. Use of alternative encapsulants, tailored to the waste material to reduce reactivity and potentially reduce internal corrosion and gas generation during storage; and

   II. Use of additives such as superplasticisers to improve the workability of encapsulants.

4. Store Performance and Design

This section comprises six examples of good practice, four approaches and six toolkits to promote robust store performance and design. It includes guidance on:

- Functions and purpose of a store for waste packages
- Current standard store designs
- Fundamental design requirements and system components
- How to define store longevity from life-limiting features and components
- Key factors to consider when developing environmental controls
- Setting robust operational limits and conditions

The primary function of a waste package store is to manage environmental conditions to promote longevity and maintain disposability of waste packages. While storing packages, the facility shall protect the public and environment from the hazards associated with the waste as well as complying with Licence Conditions and demonstrating that risks to workers are ALARP. This function may be conveniently divided into two components:

a. Maintain the waste packages through:

I. Provision of safe, secure, reliable and monitorable storage space for packages;
II. Preserving the future transportability and disposability of waste packages;
III. Ensuring the continued operation of handling, monitoring and other equipment;
IV. Ensuring the integrity of key components of the storage system;
V. Retaining knowledge and records of the wastes, equipment and infrastructure; and
VI. Retaining the ability to retrieve packages for export to other processing/storage plant or GDF.

b. Protect workers, the public and the environment through:

I. Containment of radioactive material;
II. Protection against ionising radiation to ensure doses are ALARP;
III. Providing appropriate security for waste packages; and
IV. Protection against criticality, where required.

4.1 Approach A9 – Development of Outline Store Design

Approach A9 (Development of Outline Store Design) provides key factors to identify a suitable outline store design - see also Figure 3 - including:

- **Waste package derived requirements -** see Section 3. The design must cater for the number of packages expected, environmental conditions necessary to maintain package longevity and manage the associated hazards such as shielding requirements. Where there is uncertainty in the capacity required, designs that ease future extension of the store should be considered. For example, the control room, offices, monitoring facilities and maintenance areas could be located at one end of the facility, enabling the store to be extended more easily if this became necessary;
- **Existing basic designs** to act as a template for the design - see subsection 4.1.1;

- **Fundamental store design requirements -** see subsection 4.1.2;
- **System components requiring up-front consideration -** see subsection 4.1.3; and
- **Decommissioning**; Features which make decommissioning easier should be considered and incorporated at the concept design phase. Design features that facilitate decommissioning and case studies have been collated by the IAEA [69].

End users for a store should be involved during the specification and early design phases. This includes operations, commissioning and construction personnel in order to improve the operability and constructability of a new or modified store. Potentially flexibility of future use of a store may also be considered as part of a wider waste management strategy. It should be ensured that contracts issued, in particular for design and build stages are suitably flexible to manage changes in lead contractor, undertake scope changes and enable early engagement with a supplier. This can lead to lifetime savings arising from changes in scope.

4.1.1 Current Designs

There are several basic store designs[TK8] used in the UK and overseas [70]. These designs strongly influence the tools which are applicable to manage the waste packages, and hence it is important to consider the designs, and their constraints, when establishing a design to take forward. A major differentiator between the designs relates to the shielding requirements necessary and hence is strongly influenced by the characteristics of the waste packages as previously described in Figure 8. The basic designs of stores are identified below, however recent store designs for contact-handleable packages adopt some features of stores for remote-handled packages:

a. **Stores for Contact-Handleable Packages:**

   I. **Vault designs**, with no additional shielding necessary from the store structure compared with the examples below; and
   II. **Hangar-type** with sheet metal walls and roof constructed over a load-bearing and waterproof floor.

Such stores allow operator access to fill the store and undertake direct maintenance, monitoring and inspection of packages and store features.

b. **Stores for Remote (non-contact) Handleable Packages:**

   I. **Vault designs**, with packages stored in flexible bay areas and shielding an integral part of the store design;
   II. **Charge plug**, with packages stored in fixed vertical arrays and shielding an integral part of the store design; and
   III. **Overpack**, with packages stored in and shielding predominately provided by thick–walled overpacks.

Such stores allow only restricted operator access, and with the exception of overpack designs will generally require maintenance, monitoring and inspection of the storage system to be conducted remotely.

A further consideration is the use of stillages, which can be used to stack packages efficiently and may also be used for disposal of waste packages. For requirements of stillages to be used for disposal see [71]. The potential deployment of stillages for interim storage should be a design consideration and treated as a component of the store's infrastructure; see subsection 4.2. However, it is recommended that stillages be well managed before import into the controlled store environment in an analogous way to packages - see subsection 3.4. They should be designed to be compatible with a suitable transport container as necessary and future lifecycle stages, including disposal.

4.1.2 Fundamental Requirements

The most significant design discriminators that should be noted in determining the outline store design, include:

a. **Waste package requirements**. Store designers should consider the types of waste packages that will be stored in the facility and the CfA that will be in place. This includes the environmental conditions and maintenance that are required to maintain waste package longevity and demonstrate disposability;
b. **Location**. The store should be sited above groundwater levels, not in flood plains, and ideally situated to facilitate future expansion if required. Coastal locations, in particular, may require consideration of chloride deposition risk - see subsection 4.2.2;
c. **Hazards**. The design must take due account of all foreseeable hazards relevant to the site [72, 73], including the interaction between multiple hazards. Notably, these include climate change effects such as sea level rise - see Reference [70] - and tsunami. The design of the facility should prevent in–leakage of water - see subsection 4.2.2;
d. Regulatory and legal requirements, including:
    I. **Health and safety, including nuclear safety.** For example, the Construction (Design and Management) Regulations 2015 (CDM) [74] - see also HSE guidance on its implementation, which require clients, designers and contractors to consider health and safety during the construction, use, maintenance and demolition. Store designers must make adequate provisions to ensure that the store and associated equipment can be safely maintained, such as considerations for fire safety, operability and ergonomics (e.g. having a heated control room). The design of a store should be carried out in accordance with good engineering practice and focus on the primary need of the store to manage the waste packages;
    II. **Environment**. For example, minimising carbon footprint, application of the waste hierarchy, avoiding secondary wastes, authorised discharges and preventing animal ingress. Consideration should be made of the eventual need to decommission the facility [75] and minimising its impact [31];
    III. **Security**. The outcomes articulated in the ONR's SAPs [76] must be met; the licence holder must be able to demonstrate that their security plans have met these outcomes through Claims, Arguments and Evidence.
    These plans will describe the measures intended to provide 'defence in depth' so an adversary can be detected and intercepted before assets are compromised. Thus, a combination of physical measures will be needed, although the exact requirement will depend on the physical properties of the store, the storage medium and the inventory held. Operators must confirm the categorisation of the inventory for theft and sabotage and carry out a vital area assessment to identify the standard they will be required to meet. The design must take account of likely changes to security arrangements on the site as a whole while the store is operational. They are advised to discuss their plans with the relevant ONR-Civil

Nuclear Security (CNS) site inspector at the earliest opportunity - see GP1 (Stakeholder Engagement) - to ensure these are acceptable and to see what impact the plans may have on existing security arrangements at the site. It is recommended that the applicable security standards and measures to be implemented are agreed with ONR-CNS at an appropriate stage in the design process to avoid the additional costs of retrofitting;

IV. **Transport**. For example, consideration of access to rail heads and/or a suitable road network for compliance with extant transport legislation; and

V. **Planning**. It is recommended that planning constraints, which may impact on the import schedule of a GDF, or restrict the import of packages, be managed strategically - see GP14 (Local Planning Constraints). For example, there may be a need to consider the space requirements if further store construction is necessary.

e. **Strategic and economic factors.** All future designs should be based on the need for the store to be part of an overall storage asset in the UK and compatibility between different waste management strategies, package designs and integrated waste management should be considered where practicable. Consideration of opportunities to consolidate package storage, potentially at other licensed sites, and developed as part of a wider stakeholder consultation process should be made when consistent with national government policy, local authority planning policy, safety, security, environmental, transport and any other relevant legislation, and shown to be cost effective; and

f. **Sustainability.** As outlined in subsection 2.4.5, a set of 'guiding principles' for stores have been established to support sustainability across the whole lifecycle of waste packages and stores ([TK24]). Where applicable, BREEAM may also be used as a suitable assessment framework to support sustainable design and construction of radioactive waste stores. Sustainability should be considered at the earliest stage, prior to design work for the facility.

The design and operation of a store is underpinned by the nuclear and environmental safety cases which provides a framework for hazard and risk management, as well as the derivation of appropriate WAC.

4.1.3 Significant System Components

The principal system components which will benefit most from upfront consideration include:

- **Structure and containment.** Maintaining a watertight exterior is essential for any store. Water ingress could lead to an increase in relative humidity inside the store and ultimately increased package corrosion;
- **Ventilation**. Whether or not a forced ventilation system is needed should be assessed based on significance or risk. Comprehensive Guidance is available in '*An Aid to the Design of Ventilation of Radioactive Areas*' [77]. For further details on filtration and supply air configuration, refer to subsection 4.3.3e and the reference document;
- **Environmental controls and monitoring systems**. Environmental controls should be considered for both planned and existing stores - see subsection 4.3. Monitoring systems and alarms will need to be provided to record normal conditions and detect off-

normal conditions. Depending on storage philosophy and environmental control approach, monitoring may include parameters such as air temperature, relative humidity, chloride levels, build-up of flammable gases and water ingress; see subsection 6.2.2. This should also include data management systems to align with subsection 6.9;

- **Import and export infrastructure**. This includes the need for handling equipment (e.g. cranes, forklift trucks) with the capability to deliver adequate throughputs of packages and upgradeability to accommodate other package designs, if necessary, in the future. The export facility must be capable of interfacing with the transport system design set out in the Generic Transport System Design for a GDF as appropriate - see subsection 5.1.
    - Consideration should also be given to the software used for store management and how easily it can be reconfigured to accommodate alternative package designs;
- **Emplacement approach**. The key factors affecting waste package longevity within a store can be grouped into three areas and includes the physical location of the packages in the store. The design should consider the practicability of package emplacement approaches with due consideration of package inventory and planned package arisings. However, the safety of the store and hence its design should not be dependent on a particular configuration of packages; see subsection 5.2; and
- **Storage system inspection and maintenance**. The design should cater for monitorability of the storage system, and provide a proportionate amount of space, e.g. based on the package categorisation, for intervention if packages evolve in an unexpected manner, including space for overpacks and quarantine areas, and provide maintenance bays for cranes (see subsection 4.1.4) and other life–limiting components as appropriate; see GP15 (Store Design – Monitorability) and subsection 6.2.

4.1.4 Cranes

Case studies and recommendations for crane design and operation are collated in [78]. These include:

- Creation of large Crane Management Areas for Remote–handled Intermediate Level Waste (RHILW) store;
- Segregation of crane rails from shielding and building walls; and
- Installing microphones on cranes for early fault identification.

Maintenance and potential contaminants (oil) should also be considered - see subsection 4.3.3c.

4.2 Approach A10 - Store Longevity

Approach A10 (Store Longevity) comprises the following steps to determine the store longevity and assess its adequacy of both existing and planned stores:

- Establishing the target design life - see subsection 4.2.1;
- Identifying the life-limiting features - see subsection 4.2.2;
- Considering the need for refurbishment and replacement - see subsection 4.2.3; and
- Establishing appropriate quality controls - see subsection 4.2.4.

Figure 10 taken from Reference [70], illustrates the components of the store that would be expected to remain in place for a full design life of at least 100 years, and the components that would need to be maintained and replaced. Replacement of complete stores should be avoided where practicable [3], except for sites in Scotland where second generation storage facilities may be required in delivery of Scottish policy [6]. At the design stage, optimisation for a store to deliver an extended lifetime and sustainability should be considered - see subsection 2.4.5.

The store longevity may be defined by the life-limiting feature with the shortest lifetime and which cannot practicably be replaced or refurbished. If the store longevity is lower than the target lifetime, then for planned stores the design of the storage system should be reconsidered, or other opportunities be explored to transfer the packages elsewhere.

Approach A10 comprises several activities associated with Asset Management. Asset Management is an internationally recognised approach to ensure that an asset, in this case a store (supporting the waste package and the facility itself), is managed to ensure its satisfactory operation through to final disposal (waste package) or decommissioning (facility). Application of Asset Management principles is discussed further in subsection 5.5.

Asset Management requires understanding and control of the lives of the systems and components within the store, and how they interact with the planned package lifecycle. This understanding also includes the risks associated with the sustainable operation of the facility; for example, understanding that systems will need to be periodically replaced to mitigate inherent risks within those systems, or within the facility as a whole. These are considerations for both target design life and life-limiting features.

4.2.1 Target Design Life

For new stores, the design life should typically be at least 100 years and any requirement for store replacement earlier than this should be avoided. For any existing stores where the design life does not meet this design target, consideration should also be given to store refurbishment or transfer of packages into a modern store [1]. If it is proposed to use an existing structure, modified as appropriate, as a store, it should be demonstrated that the structure meets modern construction standards, the materials chosen for any modification work are appropriate, and the resultant store is consistent with a design life target of at least 100 years, unless a shorter period can be supported.

4.2.2 Identifying Life-limiting Features and Components

As previously described, to assess the longevity of an existing store or identify detailed design criteria for a future store it is necessary to consider the store's life-limiting features and components[TK8] [70]. Once these are identified this can be used to inform the maintenance and refurbishment schedules; see GP16 (Store Design – Life-limiting Components). Life-limiting features relating to the design, management and continuing operation of the store include:

a. Design life, which should include consideration of the external factors such as floods, earthquakes, tsunami, strong winds, climate change, malicious actions, aircraft impact, snow/ice, animal action;
b. Siting requirements, in so far as they affect the external factors listed above; and:
    - storage capacity;
    - local demographics; and

I. hydrogeological properties.

c. Regulatory and stakeholder views, including:
   - planning and permitting issues;
   - stakeholders' perceived environmental and safety considerations;
   - socio-economic factors and cost issues; and

   I. changes in legislation.

d. Structural integrity of the facility, which may be affected by:
   - subsidence and settlement;
   - concrete degradation, strength, hardness and carbonation;
   - corrosion of concrete reinforcing bars;
   - elements, such as floors, to bear loads; and

   I. structural steels and cladding.

- Maintenance and assurance of the stores - see Section 6.

4.2.3 Refurbishment and Replacement

Not every component in a store needs to last for the whole design life. At the design stage it is possible to plan to replace or refurbish various components periodically and to include specific features to enable this work to be conducted. It is considered relatively straightforward to consider replacement and refurbishment of building envelope fabrics, external ventilation systems and power supplies. However, replacement is potentially considerably more complex for cranes and equipment within the active area for some store designs and major reinforced concrete or structural steelwork building structures.

Examples of components that will need to be refurbished or replaced during the design life of the store:

a. Components that affect the structural integrity of the facility:
   - elements to exclude water and control inadvertent surface water deposited on the floor; and integrity of external cladding.

b. Components that affect the operation of plant and equipment:
   - package handling equipment;
   - lighting;
   - smoke detectors and alarms, fire suppression systems;
   - physical protection systems;
   - electrical systems;
   - communication systems;
   - passive or active ventilation and/or heating systems;
   - auxiliary systems, including water supply, drainage, gas and compressed air; and software.

4.2.4 Establishing Quality Standards and Controls

All components should be subject to appropriate quality standards and control, with enhanced standards for life-limiting features. In particular, the use of appropriate concrete grades and of Quality Assurance (QA) procedures designed to ensure that such grades have both been used and cast appropriately are a key component to meeting the design life of a concrete structure. This may include controlling the levels of chlorides and other components within the mix during construction, the homogeneity and limited permeability of the product after setting, and level of penetration of chloride and any carbonation front post construction. Provision can also be made to enhance the quality of design and increase design life by, for example: provision of additional concrete cover over any rebar; use of high-performance concrete; designing and constructing the structure according to the relevant codes with consideration given to reducing design crack width limits; and provision of additional safety margins. However, performance requirements should also be balanced against cost and environmental impact of excess materials.

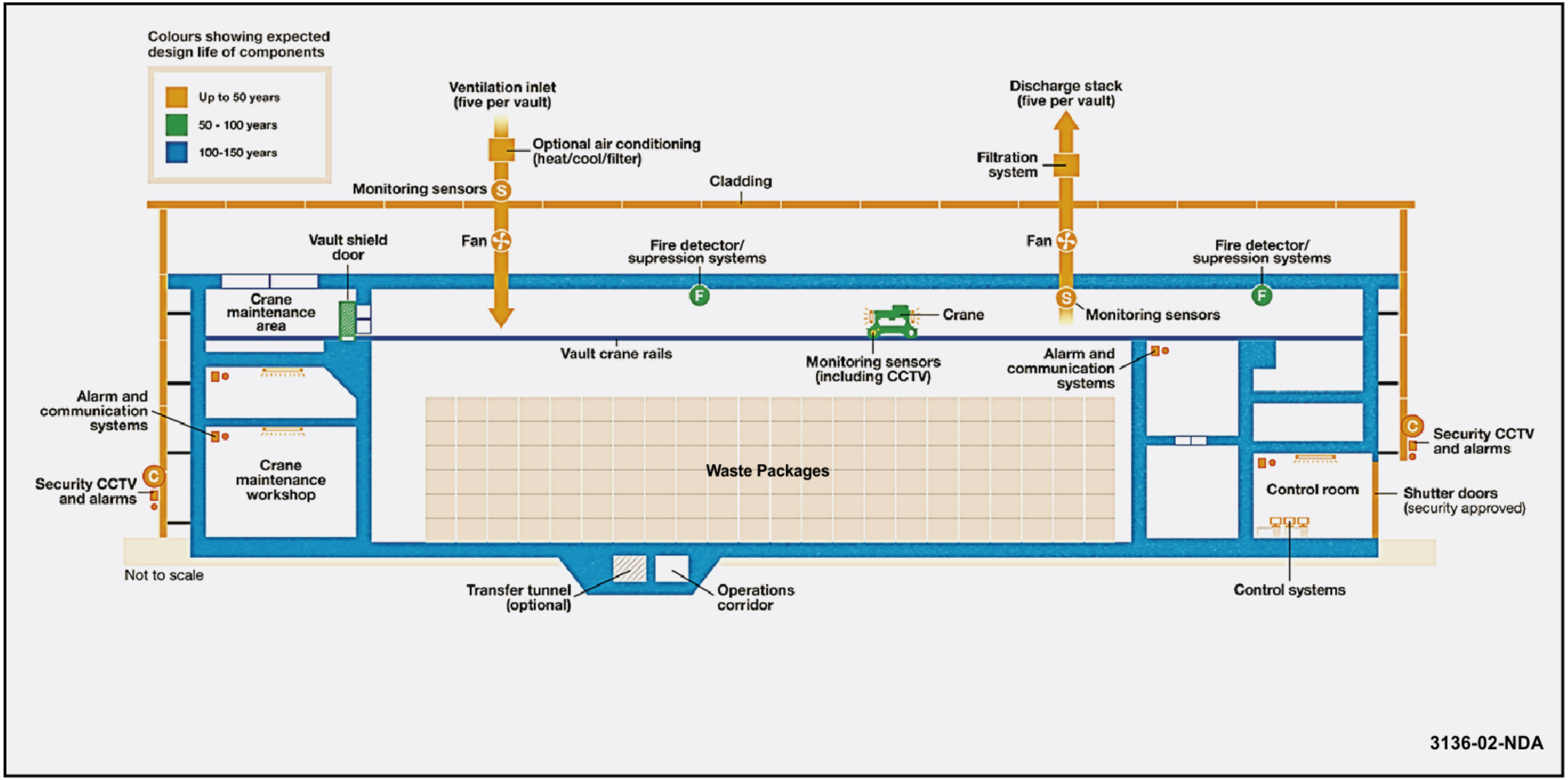

Figure 9 Representation of a Shielded Vault Store with Component Lifetimes.

4.3 Approach A11 - Environmental Controls

Approach A11 (Environmental Controls) should be considered for both planned and existing stores, given the fundamental importance of the store environment; see Figure 5.

A11 comprises the following steps:

- Setting control objectives - see subsection 4.3.1;
- Identifying constraints - see subsection 4.3.2; and
- Identifying which parameters to control and how - see subsection 4.3.3.

4.3.1 Objectives

The overall objective should always be to protect the package and the store's life-limiting components over the period of storage. This will usually mean:

- Avoiding extremes of heat and cold;
- Avoiding condensation, that is keeping the temperature above the dew point. It is important that cycling of wetting and drying events - see GP17 (Store design – Environmental Controls) - are avoided, since, in the presence of contaminant salts, such cycles are likely to maximise the probability of initiating corrosion processes as any salt solutions become concentrated as drying occurs, or dried salts initially re-dissolve;
- Controlling potential contaminants, for example aerosols or biological residues through suitable filtration systems;
- Considering the importance of the design configuration. Design features can significantly minimise the risk of contamination by considering the location and position of vent inlets, cascade vent systems and protection of top of stacks;
- Providing homogeneous environmental conditions spatially through the store;
- Protecting the capability, to finish the packages; and
- Considering issues associated with transient conditions, for example when packages are imported into or exported from the store.

Once these generic needs are considered, store-specific OLCs should be derived that take account of the store's specific context - see subsection 4.4. For example, where overpacks are used, the environment within the overpack should also be considered and suitable controls established alongside those for the main store. For such systems, there may be flexibility in developing two sets of OLCs (i.e. 'internal' and 'external' to the overpacks), depending on the materials employed in the storage system.

4.3.2 Constraints

- The storage system design should adopt a weakest link principle such that the package or life-limiting feature most dependent on environmental controls is used as the 'yardstick'. This is particularly applicable if interim products are to be stored alongside disposable products. If the resulting requirements are judged disproportionate, alternatives for waste processing, package designs, store design, or storage arrangements of the packages should be considered. In stores with non-contact handleable packages, store equipment may be difficult to access, and the environmental controls should take this into consideration, including through the use of inactive samples - see subsection 6.5;
- Passive systems should be favoured where feasible, but adopt active systems as required with due consideration of response speeds required under fault conditions.

For example, Reference [31] states that it may be necessary or advantageous for some active systems to be in place. In such cases, the systems should be designed for minimum maintenance and, in the event of failure, immediate repair or replacement should not be necessary in order to ensure continuing safety of the storage system. Where active systems are adopted, they should incorporate passive features, and be reliable, long lived and easily maintained. Hence, the environmental control approach needs to reflect carefully on this latitude to achieve the most appropriate end point;

- Maintaining disposability, should consider industry guidance and any other future finishing, storage or disposal requirements. Any caveats noted in relevant Letters of Compliance (LoCs), concerning the environmental controls, should be observed. Maintaining the environmental conditions of transportable packages, where prescribed, should also be observed;
- Location, including:
  I. the composition of salt deposition in the locality of the proposed store - see GP18 (Store Design – Contaminants);
  II. potential extreme weather events and likely future climate changes over the next 100+ years; and
  III. consideration of prevailing winds and ensuring that access points and ventilation systems (including orientation of air inlets) are designed accordingly, particularly if passive ventilation systems are adopted, to ensure a suitable store environment.
- Availability of existing site infrastructure such as power supply and its adequacy to provide suitable environmental conditions.

4.3.3 Key Parameters

The following parameters may need to be controlled as part of an effective approach:

a. **Temperature and relative humidity**. The following key aspects are noted:
   - stores relying on steam heating may be vulnerable to cycles of condensation in the event of heating failure and should be avoided where practicable;
   - Contaminants should be excluded where possible using appropriate mitigations. If practicable the target relative humidity (RH) of the environment should be tailored around the nature of the contaminants potentially deposited on store life-limiting features and waste packages; and
   - Controls (Temperature and RH controls[TK10]) include:
     - passive controls reliant on the store design features;
     - actively managed Heating, Ventilating, and Air Conditioning (HVAC);
     - ensuring prompt closure of ingress and egress doors when not required; and
     - a contingency plan should be established if the primary method fails to deliver the required performance or breaks down during operation.

   In all cases, the performance of the temperature and RH controls should be established during commissioning. Off-the-shelf solutions are preferred to bespoke equipment so that any repairs necessary can be more readily undertaken, with a reduced potential for operator errors. Internal package stacking arrangements may affect air flow through the store and have the potential to create stagnant spots where temperature and humidity depart from ambient conditions; see also bullet (e).

b. **Moisture**. Pertinent aspects include consideration of:

I. **Internal sources**, which should be controlled, but which are likely with time to diminish or at least tend towards the ambient conditions exerted by the store, include:
- the store materials, including concrete;
- waste packages in which wastes are conditioned with hydraulic cements and/or packaged in concrete containers or overpacks;
- waste packages which may contain wastes previously stored in wet or humid conditions and which, although dried before packaging, may contain residual moisture;
- wet waste stored without drying or encapsulation, for example interim products; and
- Where forced ventilation systems are used the high air change rate is likely to negate these factors.

II. **Other sources,** which should be avoided where practicable, include:
- deployment of water-based fire suppressants;
- water-bearing pipes within the store; and
- in-situ decontamination of containers using water. Any washing of packages in the store should be in dedicated cells, and packages dried afterwards.

III. **External sources,** include:
- migration from surrounding soil into the foundation, or transfer tunnels, where present;
- unconditioned damp air condensing on ‘cold’ surfaces within the store;
- inadequate performance of guttering, roofs, or cladding or other advantageous openings leading to infiltration;
- infiltration of rainwater during import and export operations; and
- equipment and materials brought into the store wet, e.g. tarpaulins with pooled water.

IV. **Controls (Moisture controls[TK11] [79])** include:
- designing out the risk of moisture ingress;
- provide detectors, e.g. in sumps, so any ingress can be detected quickly and a plan for a credible method for the prompt removal of water may be developed, if required;
- adopting practices that mitigate or manage risk of ingress, where practicable;
- effective maintenance of relevant store life-limiting components;
- dehumidification, which is best performed on inlets to the store to prevent the possibility of collecting tritium which may have to be disposed via special routes and lead to secondary wastes;
- internal or external tanking, cladding or roof decking to raft, walls and roof respectively;
- Where appropriate, convection of air in stores may be promoted by placing higher heat output packages on the bottom layer in a store, so as to drive convective overturn and homogenise conditions;
- In the case in which wastes may be left to dry within waste containers, forced ventilation and intelligent use of natural convection may also be advantageous; and
- Irradiation of water/moisture in air is a potential process for the formation of nitric acid, which may accelerate corrosion of some materials. Monitoring and the use of corrosion resistant materials in high radiation areas are recommended.

c. **Contaminants**. Potential sources of chloride, and other ‘corrosive’ materials, should be identified and an assessment made of the potential impact on waste packages and life-limiting features. For coastal locations chlorides may be especially prevalent. The sources should be eliminated where practicable, or controlled, or accepted if shown to be of insignificant threat to the integrity of the storage system. Other types of contaminants, such as sulphates and nitrates, should also be identified, assessed and controlled as appropriate. Although it should be noted that these species, particularly nitrates, are typically passivating in nature.

I. **Internal sources** include: dust, dye-penetrants, grout spills, oil, grease, paint, crayon, chalk, adhesives, graphite particles, inks, salts arising from concrete structures, radioactive contamination and perspiration from fingerprints. It should be noted that salts arising from concrete are the predominant source of contamination observed and are typically passivating in nature. Presence of iron, such as carbon steel, has been observed by NWS [80] to form superficial rusted spots on stainless steel containers;

II. **External sources** include: sea salt aerosols, combustion of fossil fuels, agricultural use of fertilisers, soil, de-icing salts, animal ingress and resulting debris such as guano - see also [81] and (d);

III. **Controls** (Contaminant controls[TK12]) include:
- prohibiting the use of unapproved writing media to mark packages;
- limiting practices that may result in deposition of salts onto containers, such as dye testing and direct skin contact;
- prescribing appropriate personal protective equipment (PPE) for use during both normal and abnormal operations;
- filtration of inlet air to prevent ingress of saline, other potentially harmful particles and microbes as necessary;
- cladding or coating the internal or external concrete store/vault walls;
- covering or moving seasonally any transportable packages to avoid contamination by road de-icing salts;
- closing of ingress and egress routes when not required; and
- implementing design features such as shield plates to protect the top of stacks, can mitigate the risk of surface contamination.

d. **Microbial and animal activity**. It is recommended that, as far as is reasonably practicable, preventative measures be adopted to minimise the risk to the storage system, noting that microbes can also be transported as airborne particles. This is particularly important for interim products containing wet wastes.

I. **Potential controls** to consider (Microbial and animal controls[TK13]) include:
- avoiding surface contamination by organic nutrients, such as adhesives and debris arising from animal activity such as guano;
- keeping wastes and waste packages under controlled light conditions (e.g. dark or green light) will eliminate the possibility of algal growth, which is a typical initiating event in microbial colonisation [82];
- maintaining a low RH, where practicable, and certainly avoiding condensation events;
- ensuring the store design takes appropriate account of preventing animal ingress especially aerially mobile animals such as birds, bats and insects;

- prompt removal of any animal ingression while observing relevant legislation for protected species; and
- using particularly corrosion-resistant materials (e.g. higher stainless steel grades) and double-skinned containers.

e. **Ventilation.** Relevant considerations include:
   - using CFD modelling to develop a fit-for-purpose approach to identify and design out potential ‘stagnant spots’ and environment heterogeneities; and avoids accumulation of any flammable gases, e.g. when combined with output from computational tools, such as MAGGAS - see subsection 3.3.3. The build-up of other gases involved in atmospheric corrosion of metals, e.g. nitrogen oxides, sulphur oxides, hydrogen sulphide, organic acid vapours, should also be controlled as far as practicable. Deployment of modular units to provide uniform conditions across the store may be considered;
   - recirculation of air should be considered in the design of the ventilation system to limit the intake of ‘outdoor air’. This could reduce operating costs, and potentially lower intake of contaminant aerosols and provide more stable temperature and RH but may raise issues in terms of accumulation of hazardous gases;

   I. ducted mechanical air systems may lead to negative pressures and may promote infiltration of external (unfiltered) air. Systems should be well sealed with a good cladding system. Poor store maintenance could also result in uncontrolled pathways forming;

   - air outlets may also need filtration to scrub radioactive gases or prevent infiltration if the ventilation system were to fail. Appropriate filters should be matched to particulate sizes, e.g. HEPA or coalescer; and

   II. forced ventilation may be advantageous in cases in which waste is left to dry naturally.

4.4 Approach A12 - Environmental Operational Limits and Conditions

Approach A12 (Environmental OLCs), set out in the following subsections, describes steps to establish a robust set of environmental OLCs with which to maintain the storage system in a safe state. A12, which should be applied in parallel with A11 (Environmental Controls), comprises:

- Establishing which OLCs parameters to prescribe - see subsection 4.4.1;
- Establishing robust limits - see subsection 4.4.2; and
- Maintaining set OLCs - see subsection 4.4.3.

4.4.1 Defining Parameters

It is recommended, as a minimum, OLCs be set for the key environmental control parameters; these are: RH, Temperature (T) and risk factors related to the presence of potentially corrosive contaminants such as chlorides (Cl^-). While the surface concentration of these contaminants is not directly measurable, it is a factor that requires careful management and mitigation - see GP19 (Operational Limits and Conditions). Whereas, the significance, and hence any latitude concerning their setting, may vary between different storage systems designs; these parameters are considered to usually be the most relevant to waste package performance and life-limiting features.

In theory, each parameter (RH, temperature and deposition of contaminants) could be independently controlled, for example using forced ventilation, heating and HEPA inlet filtration, to virtually exclude the possibility of corrosion and other package degradation processes. The controls associated with temperature and RH will often involve a form of measurement. Deposition of contaminants are managed differently. However, in practice (and where practicable) all three parameters should be managed in concert to provide defence in depth.

Additionally, the Joint Guidance [31] states that OLCs should be considered for other parameters and factors; these include: heat generation from packages; gas generation which may present hazards such as fires; radiation protection aspects; and criticality. Such consideration is likely to be highly context specific.

4.4.2 Setting Operational Limits and Conditions

It is recommended that when setting OLCs, store operators apply an approach analogous to A1 (Package Performance), and hence that setting OLCs should be considered, partly, as a risk management endeavour. Thus, OLCs should be set with consideration of:

- A de minimis level of risk such that observance of an OLC, if practicable, would essentially result in a very low risk that the storage system would not perform as safely as expected due to the environmental conditions;
- A tolerable level of risk such that observance of an OLC would be acceptable, although contingencies may be necessary and the system may need to be subjected to additional monitoring and inspection if necessary; and
- A time-limited level of risk which may be acceptable during transient conditions and would require, ordinarily, high levels of monitoring and inspection with credible and rapidly deployable contingencies.

The OLCs should be established for the waste package and/or store life-limiting feature most vulnerable to the expected environmental conditions and will usually be determined by the material of construction of that component.

In long-term storage of waste packages, some general principles are relevant to all package and store types:

- Avoid extremes of temperature, either high or low, and as far as practicable maintain temperature and avoid disruptive effects on specific materials (e.g. concrete), and contrasting air and waste package surface temperatures due to thermal inertia, potentially leading to condensation/deliquescence;
- Avoid major fluctuations in RH – transient conditions increase the risk of condensation/deliquescence and may increase the risk of corrosion mechanisms occurring in specific RH ranges (e.g. SCC[1]); and

[1] In general, it is recommended that cycling of conditions is avoided - see GP17 (Store design – environmental controls) – although existing evidence indicates that periodic cycling does not have a detrimental effect.

- Prevent ingress of corrosive contaminants into the store, including salt particles and aerosols from external sources[2], or chloride/organic acids from handling (e.g. contact with bare hands).

In addition to these general points, some more specific factors may be considered dependent upon the package type being stored. Robust shielded containers and packages, such as 6m^3 boxes and DCICs, will typically be stored in unshielded stores lacking forced ventilation. On the other hand, stainless steel waste packages such as 3m^3 boxes, will typically be stored in shielded stores having a range of environmental controls. The response of a store operator to defining OLCs will reflect the local mode of storage, and whether the waste packages are contact or remote-handled.

In general, for all storage systems, the presence of bulk water, either as a condensed/visible film or as droplets on the surface of the metal, leads to substantial degradation of many engineering materials. Therefore, as a general principle, during storage the RH and temperature should be controlled such that bulk condensation and direct contact with aqueous liquids are prevented.

Increased temperature has a direct effect on many corrosion and degradation reactions, typically increasing the probability (e.g. for stainless steel) and/or the rates (e.g. for other types of steel or for steel reinforcement in concrete) of degradation mechanisms. For this reason, notwithstanding the need to maintain low values of the RH (and hence the temperature above the dew point), temperatures should also be kept as low as practicable within the optimum range. Additionally, for some grouted wastes (e.g. wastes containing reactive metals), the risk of expansive corrosion, which could lead to cracking of the wasteform and even deformation of the waste package, is also reduced by maintaining lower temperatures within the store. Maintaining low temperatures would also decrease rates of corrosion and gas generation of any wet unencapsulated wastes and, to an extent, reduce the likelihood of MIC, which may be a particular concern for some interim products.

Significant deposition of salt from the atmosphere (deposition density > 10-100 µg cm^{-2}) may occur over long storage periods, in all store types and on all packages, unless prevented by air inlet filtration [83]. Due to the hygroscopic nature of salt, the formation of an aqueous solution on exposed surfaces is likely to occur even at RH below 100% (or at temperature above the dew point), i.e. in nominally dry conditions. For DCICs, concrete, and other thick-walled steel containers, the presence of salt contaminants is likely to be less significant both because of the nature of corrosion mechanisms operating in these systems and because of the more robust nature of these packages [59].

The following sections describe example of OLCs to mitigate potential degradation of stainless steel containers, other types of ferrous metal containers and infrastructure, and concrete containers and infrastructure. Other container materials are potentially available

[2] Contaminants from autogenous sources (e.g. concrete dust from the building fabric) are expected to be relatively non-corrosive, since these are largely derived from insoluble species (e.g. microstructurally bound chloride).

and could be considered for interim storage of wastes. International experience can be used to support consideration of such materials. In general, store specific factors such as the capability to deploy specific environmental control systems or to monitor package surface conditions, should be taken into account when defining the parameters and boundaries stated in a store-specific OLC, whilst maintaining the overall objective of minimising risks to package degradation.

Stainless steel containers:

As noted above, stainless steel waste packages will often be handled remotely and stored in shielded buildings with environmental controls. The environmental conditions typically found in relatively dry indoor environments would naturally preserve the material in good condition for a long period of time. Even if it occurs, bulk condensation of water may be tolerable for stainless steel, given its inherent corrosion resistance. However, for stainless steel containers, it will be particularly important to avoid contamination by chloride (a specific corrosive agent), from the deposition of marine aerosols or other sources. HEPA or coalescer filtration of air inlets will prevent ingress of salt particulates down to sub-micron sizes and is likely to remove relatively coarse (e.g. 1-10 μm sized) chloride-containing marine aerosols [81]. Suitable environmental controls and the prevention of particulate ingress are considered to be the primary means of ensuring the integrity of stainless steel waste packages in interim stores.

Illustrative environmental OLCs to mitigate the potential degradation of 316L stainless steel containers, for a storage system dominated by ‘exposed’ 316L, with the possibility of contamination by chlorides, is shown in Table 5; see NWS’s Waste Package Evolution Status Report [53]. This material is the most widely used container material and a large body of data exists for this and similar grade stainless steels under relevant conditions [60, 61].

The underpinning concept is that localised corrosion and SCC are severely inhibited at low temperature (particularly below the ‘Critical Pitting Temperature (CPT)’, which for 316L is ~20°C in NaCl), and that SCC is only observed at RH values ‘close’ to the deliquescence point of divalent chloride salts [84, 85], above a minimum surface deposition density. An important observation is that divalent chlorides ($CaCl_2$ and $MgCl_2$) are much more corrosive than NaCl [60], but also much less abundant [86]. As a result, during initial storage periods, NaCl is likely to be the dominant chloride species, resulting in relatively benign conditions.

Although the result of substantial R&D, the values suggested in Table 5 have been compiled using extrapolation and expert judgement, and should be interpreted with care, since they are based on testing over much shorter periods than those envisaged for interim storage (from a few years up to about 10 years), and cover only a relatively limited range of conditions (e.g. temperatures between 20 and 50°C). In general, maintaining values of the temperature and RH within 10-30°C and below 90% respectively, combined with provision of a suitable filtration system to exclude contaminant ingress, are expected to be adequate practical measures to avoid the risk of corrosion. Variation of RH is less of an issue if low chloride contamination is maintained. Generally, this would be delivered by HEPA filtration of inlet air and good practice in store operation (e.g. minimising periods when external doors are open).

It is noted that materials with superior corrosion resistance, such as duplex grade 2205 will provide greater flexibility and wider tolerances of OLCs due to their greater resistance to chloride-induced SCC and localised corrosion [58].

Table 5 Representative risk based OLCs for storage system with 316L-based packages, based on RWM's Package Evolution Status Report [53].

		Temperature [T/°C]			
		-10 to 10(b)	10 to 30	30 to 50	> 50(c)
		Chloride deposition density [Cl/µg cm^{-2}](a)			
Relative Humidity [RH/ %]	<40(d)	<[100]	<[10]	<[1]	<[0.1]
		>[100]	[10-25]	[1-10]	[0.1-1]
			>[25]	>[10]	>[1]
	40 to 60(d)	<[100]	<[10]	<[10]	<[1]
		>[100]	[10-100]	[10-25]	[1-10]
			>[100]	>[25]	>[10]
	60 to 90(d)	<[100]	<[10]	<[10]	<[1]
		>[100]	[10-100]	[10-25]	[1-10]
			>[100]	>[25]	>[10]
	>90(d)				

De-minimis - ideal conditions to avoid localised corrosion

Tolerable - moderate risk of pitting corrosion

High - risk of relatively penetrating damage, mainly due to SCC or MIC; only potentially tolerable as a transient condition

Notes:
(a) Based on the amount of chloride alone, assumed to be present in a soluble form in mixtures of NaCl, $CaCl_2$ and $MgCl_2$.
(b) At temperatures below 10 °C (the 'CPT' for 316L in $FeCl_3$), corrosion is severely inhibited.
(c) Limited data above 50 ºC, hence the maximum recommended temperature.
(d) Desiccation of waste packages and particular store features may define a lower OLC for RH, but no data are presently available to quantify a minimum level. Values below 40%, between 40-60%, and above 60% are expected to produce different levels of dilution of $MgCl_2$ and $CaCl_2$. Above 60% RH, wetting of NaCl is expected, but SCC is unlikely. An upper limit of 90% is recommended to reduce the risk of MIC.

3456-04-NDA

Other types of ferrous metal container and infrastructure:

Degradation of other ferrous metallic containers, such as DCICs, carbon steel or mild steel containers, will also be affected by the presence of salts, and environmental factors such as temperature and RH. However, at least over an initial period, likely to be of the order of a few decades, any corrosion process would be inhibited by the presence of protective coatings (e.g. paint, epoxy resins) or galvanisation, which are often employed in this type of design. Over time, it is possible that the protective coating would degrade, particularly in areas susceptible to mechanical fretting/damage (e.g. lifting features). Once the bare metal is exposed, general corrosion processes are likely to occur.

In relatively dry conditions (i.e. in a well-managed store), on unprotected (e.g. non-coated) surfaces, general corrosion rates are likely to be of the order of 10 µm year^{-1}, meaning that a material loss of 1 mm is expected over a period of 100 years [59]. In the case of cast iron, general corrosion rates are likely to decrease significantly with time because, as the material corrodes, the graphite contained within the structure remains as an insoluble residue on the uncorroded iron surface [59]. This layer can become relatively impermeable to the further penetration of water, forming a protective barrier that slows the corrosion rate. Although the atmospheric corrosion rate of carbon or mild steels is initially similar to that of cast iron, these steels do not contain free graphite and are therefore unable to form a protective layer. Therefore, the corrosion rate of mild and carbon steel is significantly higher over time.

Given the significant wall thicknesses of DCICs and the environmental conditions generally expected inside a storage facility, general corrosion is unlikely to pose a risk to the integrity of the containers for storage up to at least several hundred years. Nevertheless, it will be important to manage the extent of degradation processes to maintain a cosmetically acceptable appearance, to facilitate package inspection and, perhaps more importantly, to maintain the functionality of specific package features, particularly lifting features and lid bolts.

Preliminary/indicative OLCs for ferrous metal containers are provided in Table 6. These are largely based on expert opinion, since information on storage conditions for the full range of ferrous metal containers has not yet been rationalised.

Table 6 Representative risk-based OLCs for storage system with ferrous metallic packages.

		Temperature [T/°C] (a)			
		-10 to 10(c)	10 to 30	30 to 50	> 50
		Total deposition density [Σ x_i/ µg cm^{-2}] (b)			
Relative Humidity [RH/ %]	< 50(d)	<[100]	<[100]	>[10]	>[10]
		>[100]	>[100]		
	50 to 90(d)	<[10]	<[10]	<[10]	<[1]
		>[10]	>[10]	>[10]	>[1]
	>90(e)				

- De-minimis - ideal conditions to avoid corrosion
- Tolerable - moderate risk of localised rusting
- High - risk of relatively substantial damage due to general corrosion; only potentially tolerable as a transient condition

3495-02-NDA

Notes:

- At low temperatures corrosion processes are generally suppressed. However, the effect of temperature on degradation rates has not yet been quantified.
- Values of the total soluble species (particularly hygroscopic ones), including chloride, sulphate, nitrate, ammonium, and key cations. Very limited data have been gathered so far to evaluate the effect of deposition density, so the values are purely indicative;
- At temperature below -10°C, potential metallic-phase changes *might* preclude such an approach with respect to providing adequate safety functions under, for example, accident conditions;
- A value of the RH above 50% is expected to result in deliquescence, since a number of relatively abundant salts start to absorb moisture above this level. At RH greater than 50%, corrosion processes may be inhibited only with relatively clean surfaces (e.g. deposition density below 10 µg cm^{-2}); and
- An upper limit for the RH is recommended to reduce the risk of MIC. Very limited information (particularly on the effect of temperature) is available to evaluate the risk of MIC so this information should be interpreted with care.

Concrete containers and infrastructure:

Degradation of concrete waste packages, such as the 6 m^3 concrete box, including cementitious and steel reinforcement materials and external metallic features, could be affected by all of the above environmental conditions including temperature, humidity and deposition of contaminants. The key controls on concrete degradation are quality of concrete, pH, RH and carbonation by reaction with CO_2 [87]. A relatively low store temperature below 20°C combined with a low RH (<50%), where practicable, will reduce the risk of carbonation[3], and help to prevent initiation of reinforcing bar corrosion [87]. Chloride deposition on the box surface should also be kept as low as possible during storage prior to use, packaging, interim storage and transportation, since chloride penetration can also lead to corrosion of the reinforcing bars and subsequent concrete spallation. Steel reinforcement bars should be sufficiently deep within the concrete to protect the bar from corrosion and therefore mitigate the risk of concrete spallation [88]. Sulphate deposition may also lead to degradation reactions with the concrete and should be minimised [89].

The key factor in ensuring the integrity of a reinforced concrete container is through guaranteeing the thorough specification and quality control of the manufacturing process. A well-specified and well-made concrete will have good resistance to chloride penetration and carbonation and will protect any internal reinforcement bars from corrosion for the required duration. Evolution of the wasteform within concrete containers may be of greater significance than in metal containers, owing to the reduced tensile strength, which may make concrete containers less resistant to internal wasteform shape change.

Proposed OLCs for concrete containers are shown in Table 7. It should be noted that a chloride surface concentration is not specified in Table 7. Chloride deposition on the surface of steel reinforced packages and sulphate deposition in general should be avoided but as noted above, the consequences of any deposition that does occur will depend primarily on the quality of the concrete and *inter alia* temperature and variations in RH.

The rate of concrete carbonation increases with temperature and peaks at RH between 60 and 80%. The carbonation rate will also depend on the concrete properties. A lower water/cement or water/binder ratio, and high degree of hydration, give denser concrete with less connective porosity, which results in a lower rate of carbonation.

While Table 7 indicates that relative humidity levels of less than 50% are ideal for minimising carbonation, achieving these levels in a store with relatively newly manufactured concrete packages is likely to be impractical. In line with the text above, a well-specified

[3] Carbonation is a concrete degradation mechanism that leads to depassivation of the oxide layer on steel reinforcement, making it more susceptible to chloride-induced localised corrosion. Chloride-induced localised corrosion could result from deposition of chloride on packages combined with the presence of surface moisture, leading to diffusive penetration.

and manufactured concrete package will be resistant to carbonation at RH levels in excess of this value.

Table 7 Representative risk-based OLCs for storage system with steel reinforced concrete packages.

		Temperature [T/°C]			
		-30 to 0	0 to 20	20 to 50	>50
Relative Humidity [RH/%]	<10		(b)	(b)	(b)
	>10 <50				
	50 to 90		(c)	(c)	(c), (e)
	>90	(a)	(d)	(d)	(d), (e)

Ideal conditions to avoid / minimise degradation of container
Elevated degradation rate of container
Significantly elevated degradation rate of container

(a) Potential for freeze-thaw damage
(b) Loss of water from concrete may lead to shrinkage and cracking
(c) Humidity conditions for greatest carbonation rate
(d) Increased water availability supports chemical transport and reactions within concrete
(e) Increased temperature will promote chemical transport and reactions within concrete

3502-02-NDA

It should also be recognised in specifying interim storage conditions that concrete packages, such as the 6m^3 box, also have external ferrous metallic features, such as twistlock pockets and collars that require corrosion protection. Discussion of environmental OLCs to protect such features is provided in earlier parts of subsection 4.4.2.

4.4.3 Maintaining Operational Limits and Conditions

Given the inherent uncertainty associated with the long-term performance of life-limiting components of stores and waste packages over timescales longer than any viable test, it is recommended that all stores share their ongoing environmental condition monitoring data via the SOF and NWDRF, particularly where these data have been collected to demonstrate performance against the established OLC. With time this may justify changes to OLCs based on collective experience. An approach to modify environmental conditions (Approach A19 - Maintaining Environmental Conditions), is described in subsection 5.4.

5. Storage System Operations

This section comprises seven examples of good practice, eight approaches and four toolkits to promote robust operation of the storage system. It includes guidance on:

- Package movements during import and export
- Package configurations as part of an emplacement strategy
- Maintaining packages, life-limiting features and the storage environment
- Avoiding package reworking
- Reworking techniques to restore package safety functions if necessary
- Changing the store environmental conditions as necessary
- Extending store lifetimes

5.1 Package Movements

5.1.1 Approach A13 – Package Import

Approach A13 (Package Import) describes steps to consider during the import phase of packages, e.g. from a packaging plant, into a store. These are:

- Complying with international requirements for any public domain transport [13];
- Complying with local on-site transfer requirements;
- Making despatch and receipt checks against store WAC/ CfA - see below;
- Handing over of package records;
- Managing any out-of-specification packages - see below and subsection 5.3; and
- Establishing the package baseline condition - see subsection 6.1 - based on either site or regulatory expectations.

Packages should not be despatched from packaging plants or donor stores unless shown to meet the receiving store's WAC/ CfA; GP20 (Import Contaminant Checks). Temporary storage of packages might be required before import to manage throughput or an effective emplacement approach. However, appropriate environmental conditions should be maintained to protect the package under any such temporary storage arrangements and be consistent with the store's OLCs and WAC. The store operator or waste compliance section should ensure all packages received are subject to a current final LoC, and that compliance with any conditions is understood and can be demonstrated. Where packages are not subject to a final LoC, the store operator should ensure that credible plans are in place to complete the development of an appropriate disposability case.

Procedures should be in place to ensure that records required for appropriate management of packages are transferred to the store operator. Noting the specific NWS requirements for waste package records to demonstrate future disposability and long-term records management requirements - see subsection 6.9.

Any packages which are out-of-specification may still be acceptable into the store, where for example the store has capability of dealing with such packages, or where there are overriding safety implications, e.g. at the donor facility. Generally, it is expected that packages arising from an extant packaging plant would be more suitably and safely reworked, if required, at source. Acceptance of any out-of-specification packages must not compromise the store's safety case following any appropriate modification. Legal and facility requirements, for transport, storage or disposal, may also change over time potentially requiring package rework to assure compliance. Procedures should be in place to manage any non-conformances identified for packages that are accepted into a store, including sufficient recordkeeping.

5.1.2 Approach A14 - Inactive Commissioning

Approach A14 (Inactive Commissioning) describes steps to consider during inactive commissioning of a storage facility. Commissioning of all stores will be subject to a “cold handling” or “inactive commissioning” schedule consistent with engineering norms. A14 is based on text from Sellafield Ltd. supporting practice documents on commissioning schedules and test documents. The underpinning information will usually be derived from the Throughput, Reliability and Maintenance (T-RAM) assurance and Safety Case requirements.

Performance tests, derived from the T-RAM will, typically, consist of Product Quality tests, process parameter and timing tests, throughput trials, reliability testing, system and area integration tests, inter-plant tests, recovery demonstrations and performance critical maintenance validations.

The Safety Case identifies fault sequences, the frequency with which they occur and the severity of the hazard they might pose to plant personnel and the public. In addition, the Safety Case identifies the preventative measures designed to mitigate the fault. Figure 10 provides a framework of issues to consider in support of the development of the Cold-Handling schedule for stores. It is good practice to run end-to-end commissioning at the earliest opportunity to identify and correct integration issues. Recovery of all foreseeable fault scenarios should also be demonstrated before active commissioning, as well as using A14 for inactive commissioning of a new store; a similar process may be needed if significant modifications are made to a previously operating store.

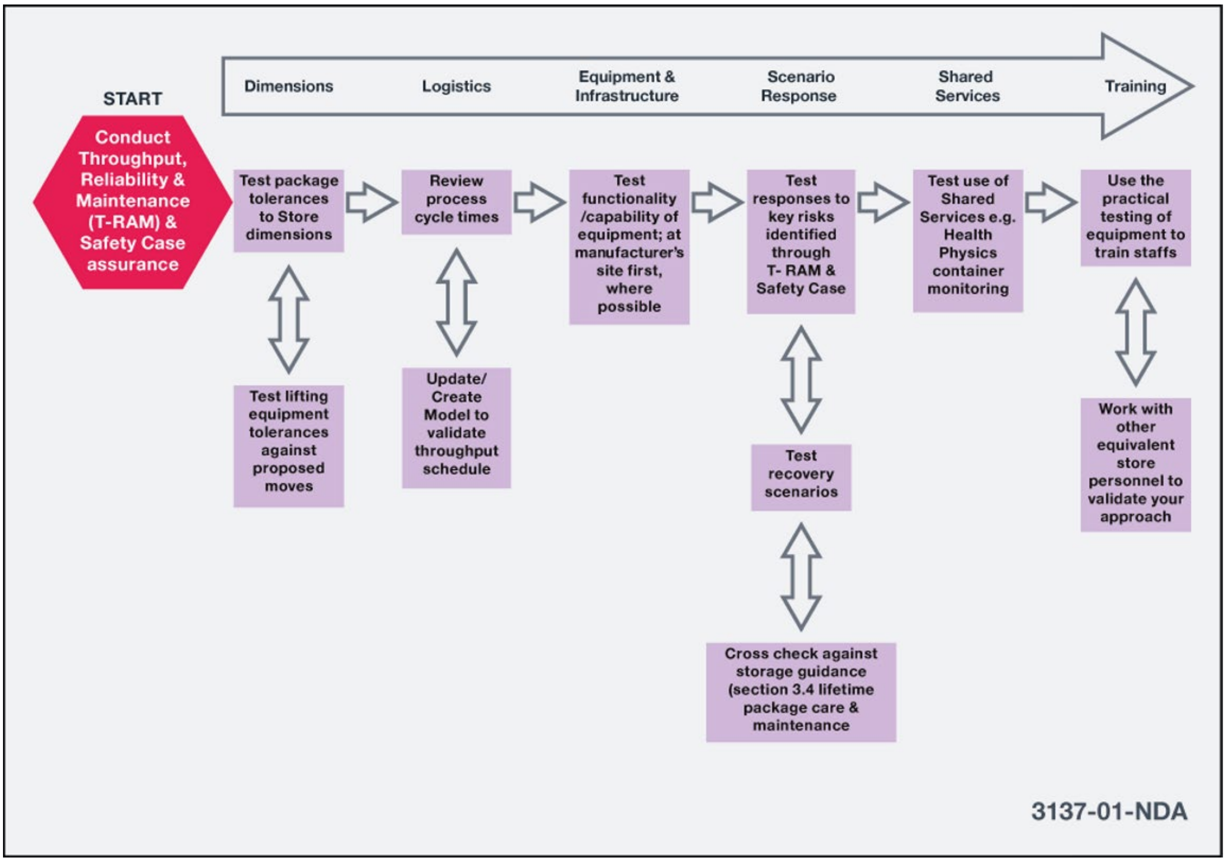

Figure 10 Indicative Inactive Commissioning Flow Diagram.

5.1.3 Approach A15 – Package Movements - Operations

Approach A15 (Package Movements – Operations) outlines steps to consider regarding package movements during the operational phase of the store. The movement of packages should be minimised as far as is reasonably practicable to reduce the risk of accidental collisions or packages becoming ‘stuck’ in lifting gear which is especially relevant in stores with remotely-handled packages. In particular, the need to consider retrievability of ‘target’ packages for monitoring and inspection, without undue requirement to access large numbers of adjacent packages, should therefore be optimised.

After import, drivers for package movements include:

- Package inspections and monitoring - see GP21 (Minimising Movements – Opportunities) and subsection 6.2.1;
- Store maintenance, e.g. to access life-limiting components;
- Demonstrating lifting equipment is still functioning safely;
- Maintaining operator skills and training and demonstrate SQEP;
- Emergency response;
- Waste receiver audits; and
- Export.

5.1.4 Approach A16 – Package Export

Approach A16 (Package Export) outlines steps necessary to export packages to another off-site finishing plant, store or to the disposal facility. Note that for many stores, maintaining the ability to export packages after a storage period of at least 100 years, and possibly longer, represents a key challenge. This challenge may be addressed through the following steps:

a. **Pre-consignment planning,** including:

   I. Confirming that each package is acceptable to the disposal facility operator, or next accepting infrastructure (e.g. store or finishing plant), and handshake arrangements including the status of the LoC and consistency with WAC. Where stillages form part of the disposal unit these should be considered at the same time;
   II. Inspection of the waste package to ensure that it is suitable for transport against IAEA regulations and the Transport Safety Case - see also GP10 (Maintaining Transportability);
   III. Ensuring approved security measures are in place, including the Transport Security Plan;
   IV. Additional substantiation or rework be carried out if the above cannot be assured;
   V. Confirm export throughput, status of lifting equipment, and access potential for interference such as possible maintenance outages;
   VI. Develop and implement a communication plan with key stakeholders and Regulators, e.g. with respect to route-planning, transport and security; and
   VII. Arrangements for the transfer of custodianship of the package records.

b. **Implementation,** including:

   I. Checks of the SWTC, or equivalent, on receipt, including identification, confirm empty and not contaminated;
   II. Provide suitable control of transient conditions such as temperature, and contaminants;
   III. Re-confirm that each package is acceptable to the disposal facility operator, or next store or finishing plant, before transport and that any modifications made following pre-consignment planning are approved by the receiver; and
   IV. Completion and collation of package records including store records relevant to packages, maintaining compliance with the requirements of the receiving site.

5.2 Approach A17 - Package Emplacement

Approach A17 (Package Emplacement) outlines steps to optimise the operation of the storage system through a planned configuration of packages within the store. However, any *requirement* for a particular package configuration to assure safety should be minimised through good package and store design - see Sections 3 and 4. The configuration should be justified within an emplacement plan, which should also note the presence of any configurations of packages to avoid. This should include consideration of the interactions between packages. It is noted that existing vault stores may have extremely limited capability for significant reconfiguration of packages. Additional information is provided in a supporting Reference [90].

a. **Assessment of benefits, pre-import planned configuration**

   For stores yet to receive packages, a planned emplacement approach can be used to *improve* the operation of the storage system, during filling, include package configurations that for example:

   I. Enhance shielding and security objectives;
   II. Improve access for monitoring and inspection of targeted packages;
   III. Reduce the overall life-time package movements, e.g. through specific layouts of aisles and package configurations;

IV. Reduce some package evolutionary processes, e.g. reducing the irradiation received by ‘targeted’ packages as may be shown to be beneficial through the LoC assessment process;
V. Where relevant, mitigate the risk of cross-contamination between conditioned waste packages and any containerised waste pending conditioning; and
VI. Enhance the effectiveness of the environmental controls.

The benefits should be compared with any identified detriments, for example, the potential need to buffer store packages to enable a planned configuration or ‘package shuffling’.

b. **Assessment of benefits, post-import reconfiguration**

Following import of actual waste packages, there may be benefits from reconfiguration of packages. For example, package configurations that:

I. Facilitate package maintenance and monitoring, e.g. moving a package with unexpected evolution into a quarantine area to safeguard neighbouring packages or facilitate additional monitoring;
II. Enhance the effectiveness of environmental controls - see subsection 5.4;
III. Facilitate exporting, e.g. packages planned for early export, where known, are re-assigned to convenient locations;
IV. Improve access to store infrastructure, including ensuring acceptable space for operators to gain access, to allow for maintenance, refurbishment or repair; and
V. A3 (Modifications to Existing Stores) should then be followed, as appropriate, with due regard of any identified detriment from package reconfiguration, e.g. from additional movements and dose to workers.

5.3 Approach A18 - Maintaining Package Performance Functions

Approach A18 (Maintaining Package Performance Functions) outlines the steps to consider with the primary objective being to avoid package rework, but if rework is required that it be carried out using appropriate tools at appropriate times. This approach is illustrated in the Package Maintenance Hierarchy shown in Figure 11.

Rework, to restore one or more package performance function, is defined [91] as:

***“Any process** involving **physical intervention** of packaged waste arising from **deviation from the planned storage**, treatment, or intended disposal process for that **packaged waste**.”*

A18 comprises the following steps:

- Avoiding the need for intervention - see subsection 5.3.1;
- Assessing package evolution - see subsection 5.3.2; and
- Identifying intervention tools - see subsection 5.3.3.

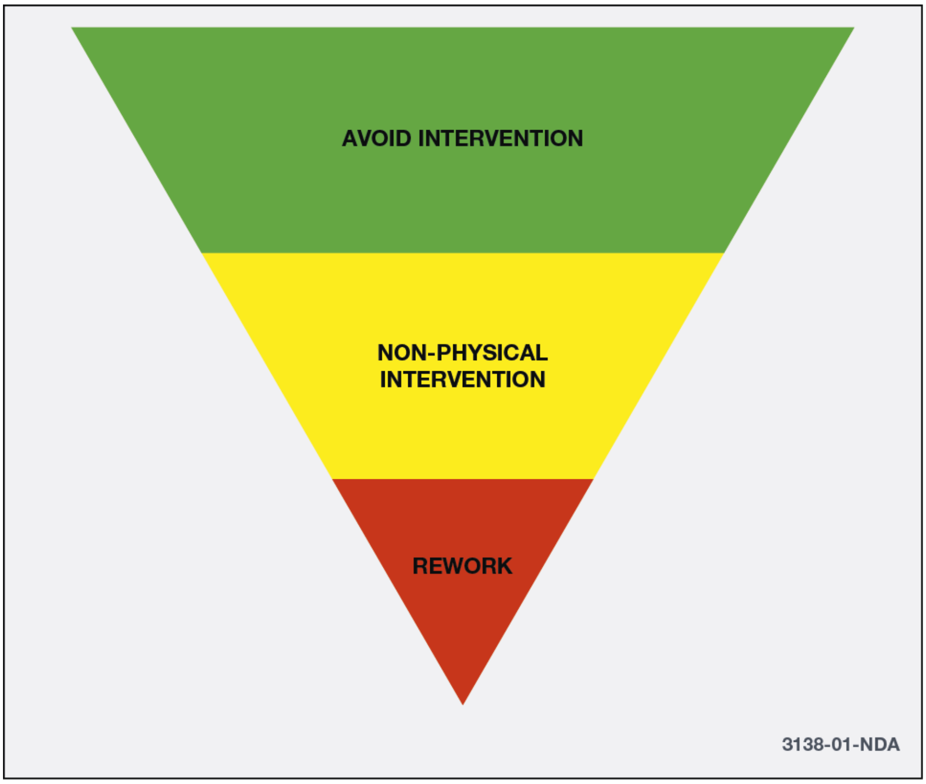

Figure 11 Package Maintenance Hierarchy.

To maintain confidence in the disposability of the waste packages, it is important that any issues relating to a non-compliant package are identified and managed. This is referred to as sentencing. Sentencing of non-compliant waste packages is expected to be regarded as an extension of the specification, implementation and operation of the packaging process itself. Notwithstanding this, sentencing needs to be undertaken with regard to the whole waste package lifecycle and so needs to consider all stakeholders, including operators of both interim storage facilities and the GDF.

It is recommended that store operators demonstrably:

- Make provision for a sentencing body to properly sentence any packages which may be considered ‘out-of-specification’ before and during storage - see GP22 (Package Sentencing Groups);
- Provide a proportionate amount of contingency space in each store to respond flexibly to unexpected package evolution - see GP23 (Maintaining Contingency Space); and
- Establish credible intervention plans for plausible scenarios according to the storage system context - see GP24 (Maintaining Intervention Plans).

The maintenance of package performance functions is consistent with a risk-based Asset Management approach (see subsection 5.5), which should be used to define the mitigation activities (risk) for package maintenance, such that the packages at all times meet their package specifications. The trigger points for intervention should be risk-based, and take into account the NDA technical aims: Safety; Security; Environmental; Whole Life Cost; Package Lifetime and disposability requirements of 150 years (NWS ‘shall’ requirement) and 500 years (NWS ‘should’ requirement following the manufacture of the waste package; store operational life (100 years England and Wales, 300 years Scotland) [37]; and package export). Derivation of trigger points should also consider ALARP arguments for the lifecycle of the package and requirements for potential rework of packages.

5.3.1 Avoiding Intervention

Store operators should follow the other approaches and good practices where practicable (e.g. setting and monitoring of store OLCs - see subsection 4.4), backed up by a robust assurance programme - see Section 6 - to minimise the risk that packages may need to be reworked to restore their safety functions.

However, some packages might evolve more rapidly or in an unexpected manner, or the storage system might not be operated in compliance with the store's environmental controls and as assessed in appropriate final LoCs, which if left unchecked might lead to the package becoming 'out-of-specification' and potentially needing rework to restore safety functions.

Packages might also become out-of-specification before receipt into the store, e.g. following packaging. While the principles in restoring such packages' safety functions may be similar, it is generally preferred that any intervention or reworking would be better carried out before import into the store - see subsection 5.1.1. However, this is not always possible or practicable. Therefore, while pre-import interventions are preferable, robust procedures should also exist to ensure safe, compliant handling within the store when necessary. Guidance is provided by NWS for the management of the compliance of waste packages as set out in the joint guidance issued by regulators and on the sentencing of out-of-specification packages [92]; this also outlines the constitution of a 'sentencing body'.

The aim of the NWS AoD process is to minimise the risk that the processing and packaging of radioactive wastes results in packages incompatible with transport to and disposal in a GDF, as far as this is possible in advance of the availability of WAC for a GDF. NWS notes the possibility [92] that as the WPS is developed into WAC then previously defined out-of-specification packages might be redefined as being compliant with a GDF.

5.3.2 Assessment of Package Evolution

A1 (Package Performance) should be used to plan for normal package evolution and assess the implications of unexpected package evolution. In the case of interim products, e.g. containerised raw wastes, a higher level of monitoring and inspection of waste and package evolution may be required.

It is assumed that packages are subject to a monitoring and inspection regime focussed on the appropriate indicators - see subsection 6.2. However, A1 should additionally be applied across groupings of packages, to identify four different patterns of potentially unexpected behaviour:

- **Type I:** one-off or sporadic packages without any obvious correlation or pattern;
- **Type II:** groups of packages with similar composition and packaging history;
- **Type III:** groups of packages with similar location in a store; and
- **Type IV:** widespread throughout a store largely independent of package type or location.

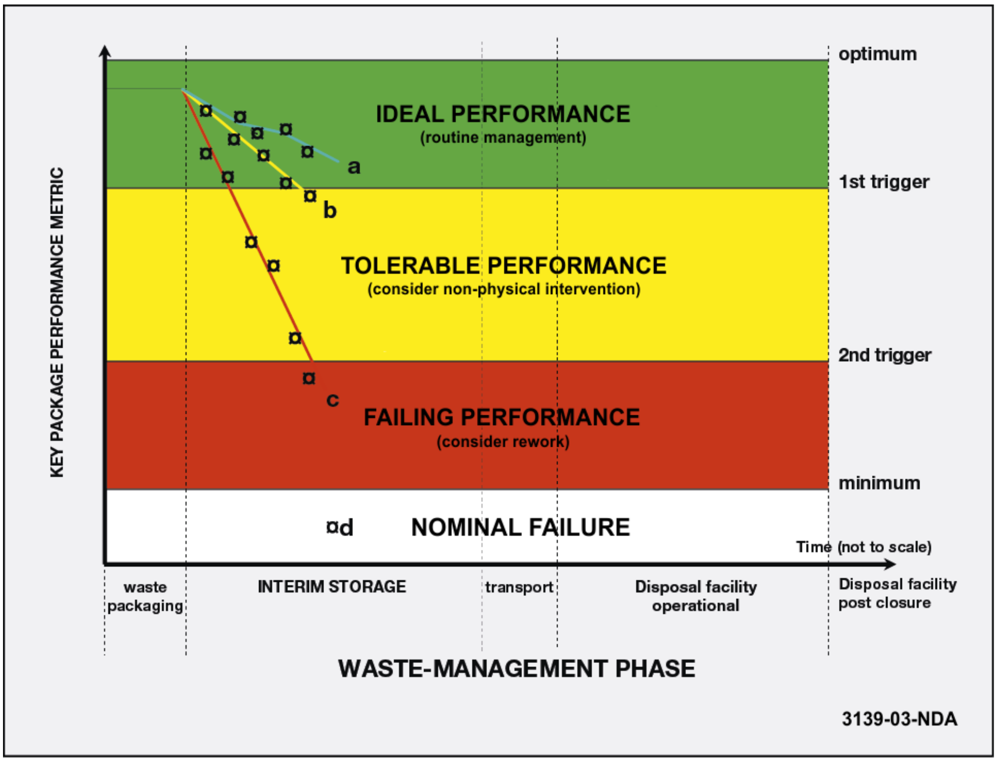

Figure 12 Hypothetical Patterns of Package Evolution.

The fundamental consideration concerning package evolution is the **extent of 'threat' to the relevant safety functions** required to preserve the disposability case and continued safe storage - see subsection 3.2. Examples of stylised package evolution are shown in Figure 12, which also includes a hypothetical 'envelope' of performance expected at the time the NWS endorsement was issued. Thus for:

- **Case (A):** where performance has declined, is within the ideal zone, and/or within the expected 'performance envelope' established when the LoC was issued, then 'no intervention' would be necessary.
  Generally, within the ideal zone, the performance should be recorded and any trends identified to inform future monitoring or environmental control opportunities identifying any behaviour Types as appropriate. If downward performance is widespread that is Type II, III or IV behaviour and unexpected, that is outside the expected performance envelope, then non-physical intervention may be optimally deployed. Additionally, for Type III or IV behaviour, changes to the environmental controls may also be beneficial - see subsection 5.4;
- **Case (B):** where performance has evolved to be just below the 1st trigger level and is within the tolerable zone, but just outside the expected performance envelope, then prompt non-physical intervention should be considered to maintain safety functions in the first instance.
  Generally, within the tolerable zone, the performance should be recorded and any trends established to identify the behaviour type. Any intervention should, in the first instance, seek to establish the cause of the performance decline as soon as is reasonably practicable - see toolkit in Table 6. Then an assessment of any implications to the safety functions should be made. Once the behaviour is understood, and the implications bounded, the timing for any further intervention if required, including later

planned reworking if necessary - see Table 7. If future performance can be maintained, using non-physical intervention, then any necessary reworking to restore safety functions could be delayed until shortly before package export. For Type III or IV behaviour changes to the environmental controls are likely to be necessary - see subsection 5.4;

- **Case (C):** Where performance has evolved to be just below the 2nd trigger level and is within the failing zone, and substantially outside the expected performance envelope, then prompt rework should be considered to restore the safety functions.
  Within the failing zone, the performance should be recorded and any trends established to identify the behaviour type if not already. If not known, the cause should be established as soon as is reasonably practicable - see toolkit in Table 6 - and followed up by appropriately timed rework - see case (b) criteria and toolkit in Table 7 - with due consideration of the current stage of the lifecycle and availability of reworking facilities to restore package safety functions. Where reworking capability is not readily available, affected packages should be moved to quarantine zones as soon as is reasonably practicable in preparation for reworking and isolate failing packages. For Type III or IV behaviour changes to the environmental controls should also be carried out to control future evolution - see subsection 5.4; and
- **Case (D):** Where performance has evolved to be below the minimum performance level, and indicates nominal package failure, then reworking should be considered to restore safety functions as soon as is reasonably practicable. Proceed as for the failing zone, noting the additional safety risks implied. If, for example, the containment safety function has been lost, the implications are likely to be significant and the store may need to be operated under ‘abnormal operating conditions’. The response to such an eventuality is not within the scope of the Guidance.

5.3.3 Intervention Toolkits

Factors influencing the identification of appropriate tools include the:

- Number of functional performance requirement(s) affected and the performance zone(s);
- Evolutionary processes involved and if cause unknown, noting the precautionary principle. Particularly the case for interim products where additional monitoring may well be warranted/required;
- Categorisation of affected packages [31] and related hazards;
- Number, location of packages affected, and category (Type I to IV);
- Risks from intervention versus ‘do nothing’;
- Internal stakeholder views - see GP3 (Technical Competence) and GP22 (Package Sentencing Groups); and
- External stakeholder views - see GP1 (Stakeholder Engagement); and lessons learned from any similar package evolution in the UK and overseas.

A toolkit comprising of non-physical intervention tools is presented in Table 8. This includes tools which seek to maintain packages safety functions, establish underlying causes of the evolution, and/or justify that the status quo is acceptable. Tools suitable for restoring package safety functions are presented in Table 9.

Given the anticipated rarity in encountering unexpected performance it is especially important that any event is well documented. Any restoration of disposability functionality must be undertaken in collaboration with NWS. This is due to the specialised nature of this performance attribute, which falls outside of the store operators remit. Additional guidance to determine appropriate tools is outlined in Reference [93]. The possibility of deploying multiple techniques in parallel and or series should be noted.

The ‘intervention’ approaches have been classified into five categories - see GP24 (Maintaining Intervention Plans):

a. **Zero Implication**. In which any action is restricted to desk studies, and expert assessment to develop an appropriate response. It is important to ensure records are retained for all responses;
b. **Low Implication**. In which any action is restricted to collating additional physical information about package performance without contacting active packages;
c. **Active**. In which any action requires changes to the operation of the storage system;
d. **Non-invasive Physical Reworking**. In which any action seeks to restore the safety function(s) by direct contact with the container and/or its components but without direct contact with or changing the wasteform; and
e. **Invasive Physical Reworking**. In which any action seeks to restore the safety function(s) by direct contact with and/or changing the wasteform.

These categories are used to define the type and level of intervention. For lower levels of intervention (Categories a-c), Table 8 presents non-physical interventions tools. For higher levels of intervention (categories d and e), Table 9 presents physical interventions tools.

Table 8 Non-Physical Intervention Toolkit[TK14].

Zero Implication
Do nothing, other than note in package and store records
Justify change to safety case such as modify performance criterion
Seek concession from disposal facility operator
Modelling to predict future performance
Additional inspection of relevant inactive simulant samples – see subsection 6.5
Low Implication
Additional inspection on relevant in-store dummy packages – see subsection 6.5.1
Increase monitoring frequency on a specific package
Increase monitoring frequency for a group or type of package
Active (involving changes to storage system operation)
Introduce new monitoring/inspection capability into store
Move package to an easier accessed area of store

Move package to dedicated quarantine area - see GP23 (Maintaining Contingency Space)
Move package to inspection cell for targeted inspection
Remote re-assay package
Change environmental controls - see subsection 5.4
Move package to alternative store with suitable environmental controls

Table 9 Physical Intervention - Reworking - Toolkit[TK15].

Physical, non-invasive (no interaction with wasteform)
Decontamination - removal of salts/inactive contaminants
Container repair - remote localised welding
Container repair - apply coatings
Overpacking, temporary
Overpacking, permanent - with infilling as appropriate
Replace container components such as bolts, filters, seals and/or lids
Physical, invasive - repackaging
Taking active samples from wasteform
Wasteform stabilisation, such as fluid grout / polymer injection
Re-containerise wasteform
Reconstitute package, such as through thermal treatment

5.4 Approach A19 - Maintaining Environmental Conditions

Approach A19 (Maintaining Environmental Conditions) outlines aspects to consider if package evolution exhibits exclusively Type III/IV behaviour - see subsection 5.3.2 and GP24 (Maintaining Intervention Plans) - or store life-limiting components are exhibiting unexpected behaviour related to the environmental conditions. Routine environmental monitoring - see subsection 6.2.2 - will be necessary to establish whether:

a. The environment has been controlled in a way consistent with the adopted environmental control approach:

I. and the storage system is behaving in a way that indicates the controls are adequate then maintain the approach as long as necessary; and
II. but the storage system is behaving in a way that indicates the controls are inadequate then the approach should be reviewed and controls established, including new OLCs as appropriate, to establish adequate performance as soon as is reasonably practicable. It may be necessary to restore safety functions of packages and store components to acceptable levels.

b. The environment has not been controlled in a way consistent with the adopted environmental control approach:

I. but the storage system is behaving in a way that indicates the controls are adequate then seek to establish the approved conditions or demonstrate current conditions are adequate as soon as is reasonably practicable, and make appropriate changes to the safety case; and
II. and the storage system is behaving in a way that indicates the controls are inadequate then promptly seek to establish approved conditions. It may be necessary to restore safety functions of packages and store components to acceptable levels - see Table 6 and Table 7.

A toolkit[TK16] for environmental control management includes:

- Reviewing relevant safety cases and justifying that conditions are adequate, or may even be relaxed;
- Changing the OLCs;
- Providing additional dehumidification and/or heating or cooling;
- Improved filtration or replace existing filters;
- Changing ventilation rates;
- Reconfiguring packages to improve effectiveness of ventilation system - see subsection 5.2; and
- Moving packages to another store noting Principle B.

5.5 Approach A20 - Maintaining Store Life-limiting Features

Approach A20 (Maintaining Store Life-limiting Features) describes key considerations to maintain the store life-limiting features - see also subsection 4.2.2. It is recommended that the International Standard for Asset Management, BS ISO 55000 series [94] be applied.

Store facilities should be maintained and inspected to ensure that structures, systems and components are able to function in accordance with the design intent and safety requirements. This should include both preventative and corrective maintenance, including:

- The integrity of the storage facility and life-limiting components, for the required duration;
- The ability to control the environmental conditions;
- The ability to operate the store and manage packages; and
- Knowledge of the structure, plant and equipment.

It should be recognised that throughout the operational life a store will be subject to Safety Case review where expected improvements will be made - see A2 (Integrated Human Factors). For example, site lifetime plans, as appropriate, should include provision for regular maintenance including major refurbishment programmes such as store re-cladding if planned operational lifetimes are significant. Consideration should be given to maintenance of the store across its whole lifecycle, including Care and Maintenance - see GP5 (Asset Management) and GP26 (Extending Store Operational Lives).

In line with GP5 (Asset Management), an Ageing (Asset) Management Programme (AMP) should be adopted and maintained during storage - see for example the IAEA peer review of the Guidance [95] and IAEA Report [96]. The transfer of information at various stages in the lifecycle of a facility is critical to the quality of information available for the lifetime management of the facility and, ultimately, at decommissioning or interim end state. Considerable effort and cost may have to be expended in order to recreate the required supporting information if information is lost, missing or insufficient. The existence of an effective AMP from conceptual design through to final decommissioning can greatly assist in the periodic assessment of a facility -see also Reference [97].

5.6 Approach A21 - Extending Store Lifetimes

Approach A21 (Extending Store Lifetimes) outlines key considerations when seeking to extend the lifetime of a store noting that the predicted lifetime should be regularly reviewed.

Guidance on techniques for extending the lifetime of existing stores and achieving design life for new stores, by the maintenance/refurbishment or replacement of life-limiting components, is detailed in Reference [70] and forms a toolkit [TK17]. Potential adverse impacts on disposability of waste packages and interim products should also be considered alongside the steps outlined in TK16.

6. Storage System Assurance

This section comprises five examples of good practice, eight approaches and seven toolkits to promote robust assurance of the storage system. It includes guidance on:

- Key components of an assurance programme
- Defining monitoring and inspection rates
- Techniques to demonstrate the system is evolving safely
- Benefits from inactive samples and simulants
- Benefits of auditing
- Knowledge management
- Maintaining SQEP resource into the future
- Records management

The main objectives for providing assurance of the storage system include:

a. Demonstrating to the store operator and their stakeholders, including regulators and NWS, that the system has been and continues to be operated as intended and evolving as expected;
b. Alerting the store operator promptly if the system is not evolving as expected and thus facilitate improvements without undue safety, environmental or economic detriment and avoid rework being necessary where practicable; and
c. Providing an opportunity to demonstrate 'strategic learning' of the performance of different storage systems to inform future store designs and current operational practices, with information shared with other operators through the SOF.

All storage systems should have a well underpinned monitoring and inspection approach. This should be proportionate to the 'risk' posed by the waste packages and their longevity [31] and the operational experience of the storage system type. The frequency of monitoring and inspection may change over time depending on whether results are consistent with expectations. These changes should be made in accordance with a site's arrangements and the impact on the waste package records also considered.

The assurance of the storage system during interim storage, should include consideration of the following approaches, in addition to A1 (Package Performance) - see subsection 2.1.3:

- Baselining - see subsection 6.1;
- Monitoring and inspection - see subsection 6.2;
- Monitoring and inspection rates - see subsection 6.3;
- Archiving - see subsection 6.4;
- Inactive waste package simulants and samples - see subsection 6.5;
- Auditing - see subsection 6.6;
- Knowledge management - see subsection 6.7;
- Human resources - see subsection 6.8; and
- Records management – see subsection 6.9.

To demonstrate robust interim storage arrangements the store operator should:

- Follow these approaches and good practices to identify, develop and deploy appropriate assurance tools;

- Ensure the waste package design and proposed management arrangements comply with relevant regulatory and NWS expectations. Packages destined for geological disposal require assessment through the AoD process - see also Section 3;
- Adopt good engineering practices and industry recognised standards and codes during the planning, construction, operations, care and maintenance and decommissioning of the store - see also Section 4;
- Retain sufficient records to provide evidence of the above, including retaining relevant records for both the waste packages and the store; and
- Feedback the findings from assurance programmes, including other relevant UK stores, into store operations - see also Section 5 and A3 (Modifications to Existing Stores).

6.1 Approach A22 - Baselining

Approach A22 (Baselining) [98], seeks to determine baseline conditions in relation to each of the storage system components, this applies to waste packages, storage facilities and environmental conditions. Once established, any departure from these initial conditions can be detected through regular monitoring and inspection as described by A23 (Monitoring and Inspection Techniques), and any necessary intervention can then be planned using A18 (Maintaining Package Performance Functions), A19 (Maintaining Environmental Conditions), and A20 (Maintaining Store Life-limiting Features).

Opportunities for baselining should be identified, noting that early baselining improves the ability to compare conditions as facilities and packages age. Typical opportunities include:

- Store commissioning;
- Production of waste packages;
- Buffer storage of unconditioned waste;
- Store import; and
- Store export.

The validity of baselines for storage system components should be periodically evaluated. For life-limiting components re-baselining may occur following routine inspections, whilst for environmental conditions this should take place annually.

In order to define the requirements and constraints for developing a baseline for storage system components the following should be considered:

- Identify plausible evolutionary phenomena based on generic phenomena described in the Guidance, information arising from engagement with NWS, and store safety case reviews. For existing storage systems, available monitoring data and records should be considered;
- Identifying safety functions and life-limiting features threatened by relevant evolutionary phenomena and prioritise these - see A7 (Package Evolution and Assessment), A10 (Store Longevity);
- Selecting suitable indicators associated with the evolutionary phenomena. Indicators for the environmental phenomena should be selected according to their significance to waste package and storage facility evolutionary processes;
- Identifying constraints on baselining, including relative ease of in-situ inspection of the waste packages and store building, plant and equipment, ease of waste package retrieval, availability of an inspection station, and presence or absence of monitoring data and records for existing stores; and

- Identifying appropriate tools and timing for baselining, considering the constraints and opportunities identified above. Develop a schedule and duration for baselining data collection. A toolkit of baselining techniques[TK18] is described in Reference [99] to support BAT/BPM assessment.

See also GP27 (Establishing System Baselines) and A3 (Modifications to Existing Stores).

The baseline condition for each waste package would ideally be fully established prior to import to the interim store, with opportunities to collect baselining data:

- On receipt of empty containers;
- During and after production of the waste packages; and
- During and after transport of waste packages to the interim store.

Baselining may also be used to establish consistency with store WAC. A baseline established after import, while still valuable, may lead to uncertainty about the likely cause and rate of progress of any package evolution. This may hamper the selection of an appropriate intervention approach - see subsection 5.3.

The baseline store life-limiting features and environmental conditions are best established during store commissioning and over the first few years of operation. However, this will not be feasible for existing waste packages and stores; available monitoring data or store and waste package records should then be used, supplemented as needed by additional baselining data collection activities.

Throughput requirements may make baselining of each package impracticable using currently available technology. Measurements of a particular indicator for some waste packages could be used to establish whether existing baselining data collated at an earlier stage are still valid for the storage period. Packages that are already in storage could be baselined at their next inspection or on a campaign basis. For existing stores, the baseline for some of the store life-limiting features could be established during the next inspection. However, the baseline for store environmental conditions needs to be established over at least one calendar year.

Baselining is likely to be considerably easier for contact-handleable packages and stores containing them. However, given the importance of baselining, it is strongly recommended that all waste storage systems identify fit-for-purpose tools.

6.2 Approach A23 - Monitoring and Inspection Techniques

Approach A23 (Monitoring and Inspection Techniques) describes steps to establish a robust monitoring and inspection regime:

a. **Selecting sample types**[TK19]. These include:
    I. in-situ components of the storage system, i.e. packages - see subsection 6.2.1; life-limiting components - see subsection 6.3.2; store environment - see subsection 6.2.3;
    II. full scale simulants or copies of system components, e.g. ‘dummy packages’ held under relevant store conditions - see subsection 6.5.1; and
    III. reduced scale simulants of system components, e.g. coupons of key components held under relevant store conditions - see subsection 6.5.2.

Additional sources of relevant information may include:

- storage system components held in other relevant stores;
- storage system components maintained in archives - see subsection 6.4;
- analogue materials either in a store or elsewhere - see subsection 6.5.3; and
- deployment of modelling and theoretical studies.

b. **Selecting attributes** to discriminate between potential monitoring and inspection techniques as part of compliance with Licence Conditions and/or a BAT/BPM demonstration. Recommended attributes include:
    I. **Safety function related**, such that output information can be related to the performance of the safety functions and maintaining package longevity and disposability - see also subsection 3.2;
    II. **Simple**, where possible techniques should be simple to procure and implement with low requirements for operator training. Complexity should be avoided where practicable;
    III. **Practicable**, such that disruption to the operation of the store is minimised and application is ALARP. Techniques employed in stores requiring remote operations should embrace ‘passive’ features with limited requirements for maintenance or ideally provide remote inspection capability;
    IV. **Credible**, such that the technique has a high Technical Readiness Level (TRL) in the nuclear industry or widespread application elsewhere;
    V. **Predictive value,** such that the information may forewarn of future issues such that any intervention required can be adequately planned;
    VI. **Reassurance value,** such that the output utilises recognised metrics which may reassure a wide range of stakeholders;
    VII. **Reliable**, such that false positive and false negative results are avoided;
    VIII. **Interpretable**, such that any output should require limited interpretation to minimise potential human error; and
    IX. **Lifetime cost**, which should be proportionate to the risks mitigated.

c. **Selecting tools from relevant toolkits** - see subsections 5.3.1-5.3.3;
d. **Establishing frequency of monitoring and inspections** - see subsection 5.4;
e. **Sharing results** with other store operators - see GP28 (Recording system performance). For further recent case studies of CM & I see subsection 5.1 of [78].
f. **Feeding back** findings into operations - see A2 (Integrated Human Factors) and Section 5.
g. **Reviewing** approach periodically. For example, as confidence in the storage system performance grows, there may be opportunities to remove inspection techniques and reduce frequency of inspections. Decisions and justification to reduce the scope of an inspection and monitoring programme should be document and reviewed against disposability requirements and compliance with relevant licences and permit conditions.

A23 (Monitoring and Inspection Techniques) as applied to packages, is represented in Figure 13.

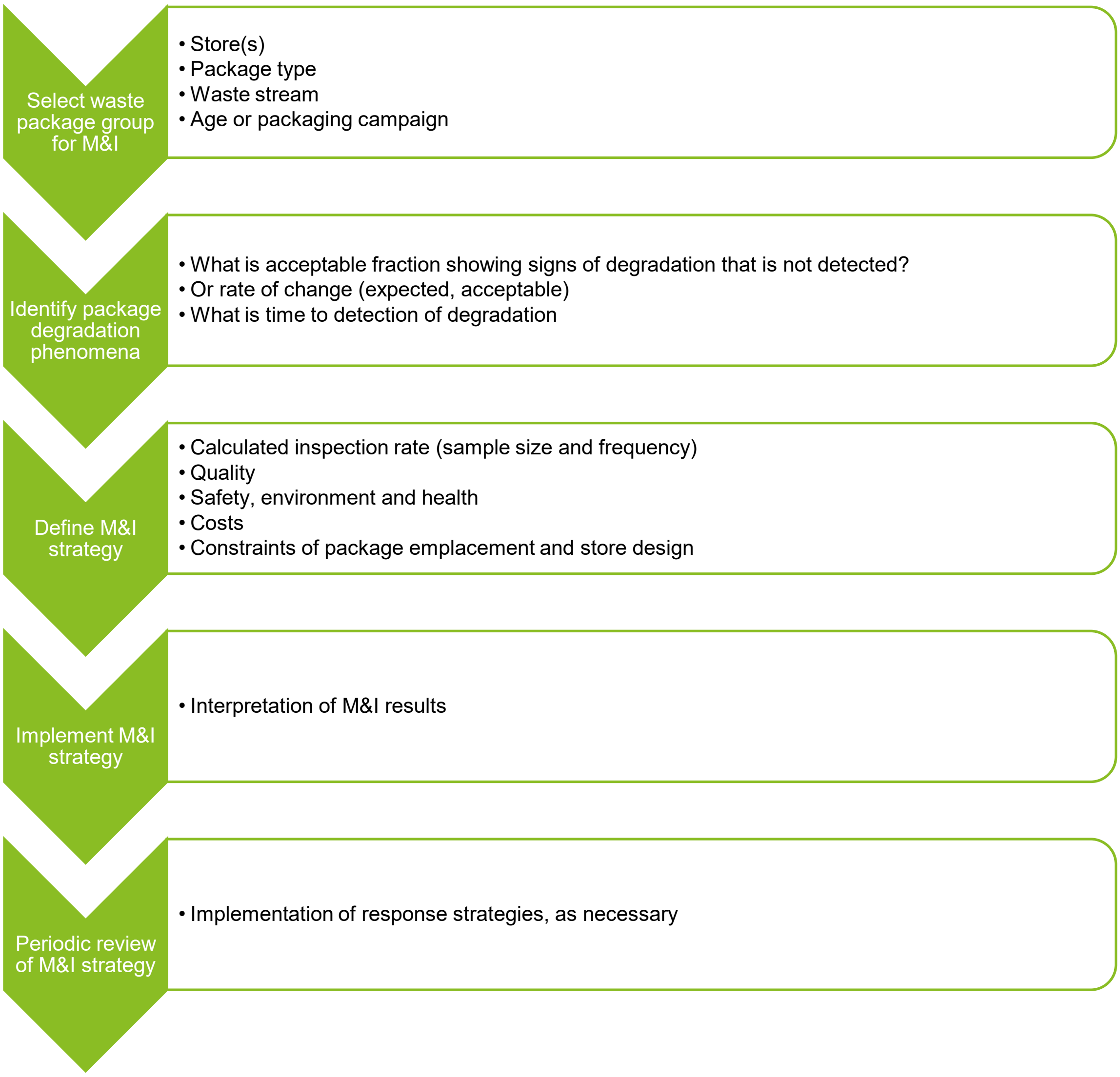

Figure 13 Simplified Flowchart of Approach A23 (Monitoring and Inspection Techniques) Applied to Waste Packages.

6.2.1 Packages

A toolkit[TK20] of over 50 techniques with the potential to provide useful information concerning the evolution of waste packages has been identified - see Reference [100]. The choice of tools should be strongly influenced by the risk level, and should involve tools that are capable of reliably indicating the performance of the relevant package safety functions - see subsection 3.1.2 in addition to the other attributes noted in A23 (Monitoring and Inspection Techniques). For existing stores, with remote handling constraints, the incorporation of additional monitoring and inspection technologies may be extremely limited. Further, the potential for damaging packages during monitoring and inspection operations, and the radiological doses associated with deploying the selected tool, need to be considered as part of an ALARP argument.

Within a waste group, specific packages may be chosen for additional monitoring and inspection, known as surrogate packages, with the results representing that of the wider group. Results from monitoring and inspection should be recorded and retained as part of both the store and waste package records, with explicit linkage to the package under investigation.

6.2.2 Environmental Conditions

Installation of monitoring equipment is best undertaken at the earliest opportunity, including during the design phase where possible. Monitoring equipment will require maintenance, calibration and testing to ensure accurate results are obtained.

Monitoring the environment can provide valuable information concerning the effectiveness of the overall storage system, and whether it is operating as expected over time - see subsection 5.4. A sufficient sample size of measurements should be made to provide a statistically significant average of internal conditions, as well as at key locations throughout and external to the store which may provide diagnostic information, for example, near ventilation inlets and outlets.

A toolkit [TK21] of environmental monitoring techniques is provided in Reference [70]. Appropriate records must be made of the measurements and reference to these made in waste package records where necessary - see subsection 6.9. Both the absolute value of the measurements and commentary of its variation with time, noting any periodicity and spatial variation, should be recorded - see GP28 (Recording System Performance). Arrangements and programmes for monitoring an inspection should be periodically reviewed based on analysis of data trends.

The following aspects are noted for additional guidance:

a. **Surface concentration of corrosion-accelerating substances**, particularly chlorides and microbes, to provide assurance that corrosive conditions are not developing within the store. Approaches include: swabbing, direct flushing and use and analysis of coupons from stores themselves or, if that was not practicable, from other suitable locations (e.g. nearby building with similar ventilation and filtration systems).

   Analysis should include determination of particulate deposition density and chemical composition of resulting leachate in water, for both cations such as sodium, magnesium, calcium and ammonium, and anions such as chloride, nitrate and sulphate. The relative ratios of ions should also be considered as this is an indicator of contaminant origin and corrosion risk; and
b. **Concentration of gases**. Monitoring for gases with potential explosive, radioactive, toxic or corrosive effects should be carried out if there is a credible risk - see also subsection 3.3.3. Notably, radon gas concentrations measurements, before and after commissioning, should be made [29]. Monitoring gas concentrations (particularly H_2 but also H_2S and CH_4) may also be valuable in confirming the nature and rate of degradation processes within waste packages.

An example of a study of environmental conditions within an operational store, sponsored by NWS, is provided in Reference [101]. This includes a description of tools deployed, results gleaned and interpretation.

6.2.3 Store Life-limiting Components

Provision for maintenance, testing and inspection should be established to address the ageing of structures, systems and components and the results from this programme should be used to review the adequacy of the design at appropriate intervals. This could include monitoring for fatigue, stress corrosion, erosion, chemical erosion or radiation induced changes.

Two toolkits applicable to unshielded [TK22] and shielded [TK23] stores are identified in Reference [70] for a range of store life-limiting components. Processes affecting concrete and reinforced steel evolution and monitoring technologies are outlined in Reference [102]. Tools include visual inspection, concrete/rebar degradation monitoring, and crane monitoring. Corrosion coupons made from store life-limiting components, e.g. crane materials, may also provide valuable information. Evidence for any animal intrusion events should be noted and acted upon as appropriate.

Maintenance, testing and inspection routines also contribute to the demonstration of compliance with Licence Condition (LC28); which states that all plant that may affect safety is scheduled to receive *regular and systematic examination, inspection, maintenance and testing* and that this be carried out by SQEP and records made. It is also a requirement of the EPR16 environmental permit (condition 2.3.4) that the operator shall maintain in good repair and (condition 2.3.5) that the operator shall check at an appropriate frequency, systems and equipment required to comply with the permit (e.g. use of best available techniques).

6.3 Approach A24 - Monitoring and Inspection Rates

Approach A24 (Monitoring and Inspection Rates) describes steps to determine a robust level for inspection and monitoring of waste packages. Aspects of A23 may also be considered for environmental monitoring and inspection of life-limiting components. It is recommended that all stores establish a target inspection rate to achieve a high level of confidence in the storage system across the period of interim storage, and that the actual frequency proposed is proportionate to the risk of degradation of the storage system. Monitoring and inspection rates should also be established based on ALARP considerations, noting the positive safety benefits realised by monitoring and inspection, and agreed with stakeholders - see GP29 (Monitoring and Inspection Rates).

6.3.1 Waste Package

A24 (Monitoring and Inspection Rates), which is widely applicable to all storage contexts, is described in detail in Reference [103] along with a supporting toolkit [TK24] to calculate an inspection rate based on a set level of confidence, or on the level of confidence given a certain rate of inspection. Both results should inform the establishment of a robust rate.

A24 (Monitoring and Inspection Rates) comprises a number of steps including:

a. Selecting common groups of packages;
    - Establishing relevant package evolutionary processes for these groups - see A7 (Package Evolution and Assessment);
    - Applying A1 (Package Performance), and selecting appropriate monitoring and inspection tools, along with applying an appropriate statistical model, for example a Bayesian method. To determine a statistical model data may be obtained or estimated from first principles or based on knowledge of the evolutionary processes and store environment conditions. Alternatively, the information can be empirical, based on evidence from other monitoring and inspection surveys elsewhere or accelerated ageing trials. Best estimate evolutionary rates can come from a combination of these approaches;

b. Defining an inspection rate based on sample size and inspection frequency;
    - Applying cost-benefit analysis - see example in Reference [103] - to assess the practicability of implementing the proposed package monitoring and inspection approach. This may include the use of surrogate packages to represent a wider group;
c. Implementing agreed monitoring and inspection regime;
d. Interpreting output, recording and sharing of results; and
e. Reviewing applied ‘approach’ periodically.

For existing stores with an already established monitoring and inspection rate, it is recommended that A24 be considered when the current approach is next periodically reviewed or when a new type of package is introduced into the store.

For new stores, minor changes in parameters related to the building or emplacement approach during the design phase may result in different output values for the frequency and number of packages to be inspected, allowing the broader cost benefit implication of the different potential inspections regimes to be explored; this also applies to the selection of new waste package designs. The cost-benefit analysis takes into account factors such as the expected long-term package performance and disposability, the cost and risk associated with inspection and the potential benefit to be gained from monitoring and inspection. The selected monitoring and inspection rate should be ALARP.

The following opportunities are noted to reduce the number of active package movements for inspection:

- In-situ inspections;
- Use of dummy packages - see subsection 6.5.1;
- Exploitation of reduced scale samples and simulants - see subsection 6.5.2; and
- Sharing monitoring and inspection results from similar stores to maximise learning via the SOF.

6.3.2 Store Environment

The frequency of monitoring store environmental conditions should be proportionate to the risk of degradation of packages and store limiting components. Where possible, equipment should be installed capable of continuous monitoring of environmental conditions. Periodic inspections, as opposed to continuous monitoring, may be appropriate for store conditions which are demonstrably stable and/or predictable (e.g. through a robust environmental model in combination with suitable baselining). In all cases measurement frequencies should be periodically reviewed to ensure that the quantity of data is sufficient to analyse and identify trends but not excessive, such that downloading and manipulating data becomes difficult. The inspection frequency of coupons, used to support environment monitoring, may be defined using A24.

6.3.3 Asset Management

Good asset management practices should be followed for the lifetime of the store - see Reference [94]. For civil structures inspection should routinely be carried out at least every five years although some components (e.g. roof or drainage) may require more frequent attention. The rate of inspection should be increased where evolution is proceeding faster than expected. Advice from a suitably qualified civil and structural engineer should be sought to determine inspection requirements and the remediation of any identified defects. Maintaining lifting equipment is a key enabler of ongoing store operations and more regular inspection may be necessary - see Reference [104] and extract.

6.4 Approach A25 – Equipment and Sample Archiving

Approach A25 (Equipment and Sample Archiving) outlines the types of materials that may be maintained to help ensure the integrity of the storage system and to support timely and safe export. It is recommended - see GP30 (Maintaining an Archive) - that each store develops an archiving plan, based on the design of the store and the characteristics of the waste packages, which identifies archiving requirements and how the store operator will retain access to:

a. **Strategic spares** of vulnerable components subject to refurbishment and maintenance, e.g. crane parts, especially where these are bespoke and unlikely to be readily available in the future. These should be utilised as necessary to preserve safe operation of the store in the future. Such an archive should be in a low radiation field environment and be under controlled conditions in an auxiliary part of the store;
b. **Components of the store's life-limiting features** taken during construction and preserved such as samples of reinforced concrete. These may inform future studies looking to establish extensions to the store's lifetime; and
c. **Inactive waste package samples and simulants** generated during waste packaging design where these represent the eventual packages and are not otherwise subject to a UK programme [105]. These could be placed in any spare full-scale container (dummy packages) within the store or in an auxiliary part of the store. Such an archive could be used to supplement monitoring/inspection, provide lead times for evolution performance and provide materials to test package repairs - see subsection 6.5.

Additional samples may be required over time to account for changes in the design of the store system, such as changes in the formulation of packaging materials. The requirement for additional samples should be considered as part of design change processes, as well as periodic reviews of inspection and monitoring.

6.5 Approach A26 - Inactive Samples and Simulants

Approach A26 (Inactive Samples and Simulants) describes opportunities to exploit the value from inactive waste package simulants and other storage system samples. The principal advantages from using simulants and inactive samples is their potential for reduced worker doses compared with like-for-like inspections of actual packages and potentially inaccessible life-limiting components - see also Reference [106]. Changes to the storage system may necessitate additional inactive samples and simulants, for example cement and concrete formulations, container coatings and inspection criteria. The requirement for additional samples should be considered during the design change process.

Simulants and samples should be retained and information about them shared with other store operators to maximise their strategic value, via the SOF. Any decision to discontinue the storage of inactive samples and simulants should be made strategically - see GP9 (Package Materials) - and offered to other stakeholders such as NWS for long-term stability underpinning, and universities carrying out fundamental research, before being disposed of.

6.5.1 Dummy Packages

Deployment of ‘dummy packages’ - see GP31 (Deployment of Dummy Packages) - can represent a valuable complementary method to support the monitoring and inspection of active waste packages [106] and otherwise support store operations and demonstrate rework activities with minimised operator risk. Dummy packages are non-radioactive full-scale packages that are demonstrably representative of active waste packages as produced.

Dummy packages can be used to develop or test methods of rework, overpacking, non-standard handling, or to allow demonstration of aged package performance, e.g. response to impact accident. Dummy packages can be instrumented to augment the environmental monitoring regime, overlapping with the role of surrogate packages within a waste group. This can produce additional monitoring information, such as providing a route for direct measurements of contaminants on realistic surfaces. Where dummy packages are manufactured with a realistic simulant of an active waste package these may provide an early warning of unexpected package evolution. Information arising from similar dummy packages held within in another store or elsewhere may also be usefully applied.

6.5.2 Reduced-scale Simulants and Samples

Where full-scale dummy packages are not practicable or economically viable reduced scale inactive simulants and samples can be deployed, commonly within a store.

Samples of relevant materials can be placed in a store to support effective monitoring and inspection. For example, corrosion coupons - see Reference [107] - are often deployed in stores to measure contaminant deposition. Additionally, inactive samples provide the ability to carry out destructive testing if required, for example to identify carbonation of concrete.

6.5.3 Analogues

Materials which are analogous to those employed in the storage system may also provide valuable information concerning its long-term evolution. Examples include ageing structures and samples on existing nuclear sites and elsewhere, similar materials utilised under harsher conditions such as on oil rigs, and coastal structures like piers and bridges.

6.6 Approach A27 - Auditing

Approach A27 (Auditing) concerns demonstrating, so far as is reasonably practicable, that adequate management system arrangements are in place for a store. This includes:

- Environmental conditions in the store;
- Monitoring and inspection of the store and storage conditions;
- Monitoring and inspections of the waste packages in storage;
- Any other activities that may be carried out that affect interim storage;
- Change control and continuous improvement;
- Production, management and long-term retention of records;
- Risk management; and
- Any other activities that may be carried out that affect the waste package lifecycle.

Quality assurance audits should be conducted by store operators in accordance with ISO9001 [108] using suitably qualified personnel. Internal auditing procedures should be in place to define the responsibilities for planning and conducting audits, reporting results and retaining appropriate records. Non-conformities should be identified and their resolution documented.

NWS seeks additional assurance of management system arrangements through the periodic review process [109]. Benefits to the store operator from the periodic review include opportunities to: share good storage practices; establish the significance of any emerging WAC for a GDF on the store operation and environmental controls; and seek advice on the management of any packages showing unexpected evolution.

6.7 Approach A28 - Knowledge Management

Approach A28 (Knowledge Management) outlines steps to ensure effective knowledge management across the storage system's lifecycle noting the inter-generational timescales. Implementation of knowledge management practices aim to support the development and maintenance of competence to operate throughout the store lifecycle; and should be implemented throughout the store lifecycle from design to decommissioning. Records management, a subset of knowledge management is covered separately as Approach A30 in subsection 6.9.

Good practice in the management of knowledge should be based on these foundations:

- A competent workforce for the design, build, operation, maintenance and decommissioning of the facilities throughout their lifetime - see subsection 6.8;
- Lessons are captured, retained and acted upon, including knowledge sharing with other interim stores and operators;
- Valid records of contents and plant configuration are kept and are retrievable and interpretable throughout the lifecycle of the store - see subsection 6.9; and
- Location of the various stores and an accurate inventory of the contents is recorded and readily understood by any agent who has the potential to be affected by or require legitimate access to the store.

A typical approach to knowledge management should consider the following aspects:

- Processes are in place to ensure that information ownership is maintained and transferred during management and operational transitions over the full lifetime;
- Ensure that store sites are mapped and described so that their locations, configuration and the inventory can be established at all times;
- Maintain skills to operate stores through training, coaching and mentoring;
- Maintain interaction with national and international communities of practice;
- Undertake knowledge risk assessments of personnel and groups that hold critical knowledge and establish plans to retain that knowledge (succession planning); and
- Systematically capture, retain, resolve and share lessons learned through national and international collaborations between operators and regulators.

Additionally, store operators are referred to a top-down approach developed by the NDA [110] for which a high-level compliance programme is underway. This aims to provide a framework across the NDA sites for managing information and knowledge assets throughout their lifecycle, to maintain consistency in their application and processing and ensure compliance with regulatory and statutory obligations.

6.8 Approach A29 - Human Resources

Approach A29 (Human Resources) comprises the following considerations.

Interim storage is a long-term activity that requires effective workforce planning to determine the best approach especially for those sites who will enter a significant period of abeyance. Workforce planning should be considered early and periodically to ensure that skilled personnel are available to support all storage activities. Models that may be considered for workforce planning are:

- A continued workforce activity at the site level as per the current baseline;
- A regional or SLC approach to workforce planning that could involve activity-specific mobile expert groups;
- An NDA or national approach to workforce planning that could involve activity-specific mobile expert groups; and
- A local approach that would involve more than one waste owner, e.g. one interim storage workforce plan for a co-generation site.

6.9 Approach A30 – Records Management

Records management is a key consideration throughout the lifecycle of both waste packages and interim stores. This includes information necessary to form part of the waste package record and those required to maintain and demonstrate safe operation of an interim store. Information and records should be managed in accordance with the NDA's information requirements [111] and include consideration of:

- Appropriate storage media and format;
- Records retention periods; and
- Custodianship and records transfer arrangements.

Additional information regarding the long-term management of records for wastes that may be destined for geological disposal have been produced by NWS [112]. This document gives further specific requirements for the storage of records over long timescales and maintaining accessibility of data and information.

Manufacturers of waste packages should ensure that sufficient records relating to the waste package are retained, indexed and transferred to store operators. Guidance on requirements for waste package records and the information that should be held in them is provided by NWS [37, 92,112]. Appropriate records of store conditions relevant to the evolution of waste packages should be maintained, along with records of interventions made as described in subsection 5.3.3. Procedures should be in place to incorporate records from the interim storage period to the waste package record. Records retained to demonstrate disposability, as per NWS requirements, should be indexed in a Package Record Specification (PRS). The PRS for a group of waste packages will require periodic update throughout the interim storage period, this should be incorporated in management plans for interim stores. In future, processes will be required for the transfer of custodianship of records upon package export for disposal. Records and information relating to the interim store should also be retained to facilitate effective operations and decommissioning. This may include:

- Maintenance of accessible libraries of documents, images, videos, drawings, graphs, other information artefacts and knowledge assets; and
- Maintenance, as part of the ageing management programme an interactive and searchable Facility Information Management system that includes the history of the facility on a variety of essential criteria, which includes: design rationale, design documentation, inventory records, plant modifications, key personnel and other operating site licence requirements.

Information management systems should be implemented at the requirements specification stage of design development and maintained throughout the store lifetime. Attention is also drawn to the importance of maintaining RWMCs to provide an accurate overview of waste management on each site [31].

For example, see Reference [113] and [114] for guidance on long-term records management.

7. Good Practices

To aid readability, the Good Practices are colour-coded as follows:

1. Overarching elements of the Guidance, relevant to all aspects of storage (white);
2. **Waste package** performance requirements, management and design (blue);
3. **Store** performance requirements, environment, management and design (yellow);
4. **Operation** of the storage system (pink); and
5. **Assurance** of the storage system (orange).

Table 10 Good Practices

GP	Description	Subsection
1	Stakeholder engagement. The Regulators and NWS should be engaged throughout the storage system's lifecycle including during the early planning stages. Other stakeholders, including Local Planning Authorities, should also be engaged as appropriate [31]. Relevant to all storage systems, especially for proposed new packages and stores, and modifications to existing storage systems.	1.3.3, 1.3.4, 5.3
2	Technical terminology. Consistent technical terminology should be used to describe all aspects of the storage system across its lifecycle. Relevant to all storage systems.	2.4
3	Technical competence. Throughout the period of interim storage, SQEP should be available, who: ○ understand the relevant package evolutionary processes and the expected pattern of package evolution during interim storage; ○ understand the significance of any indicators of package evolution outwith the expected performance at the time the packages were assessed by NWS via the disposability assessment process (and any updates thereafter); ○ can act as an intelligent customer for any related work carried out by the supply chain. Relevant to all storage systems. Noting there is greater potential to share SQEP between common storage systems.	2.4.2; 3.1; 4.3
4	Human factors. Human Factors should be applied at all stages of store design and operation and be implemented as an integrated component of robust interim storage arrangements. Relevant to all storage systems and stages of the lifecycle.	2.4.2

GP	Description	Subsection
5	Asset Management. A formal asset management approach (aligned to ISO 55001) should be applied to the risk based whole life asset management of the complete system of waste packages and waste stores. Relevant to all storage systems.	4.2, 5.3.1, 5.5
6	Research and development. The NWDRF Working Group on Storage should be consulted, before commissioning R&D to support development or operation of the storage system, to avoid duplication and promote co-operation. Relevant to all storage systems, noting the likelihood that unique designs will more likely require bespoke R&D.	2.3.1
7	Peer groups. The Store Operations Forum should be regularly engaged to share and benefit from operational 'lessons learned'. Relevant to all storage systems and stages of the lifecycle.	2.3.2
8	Package designs. Unless there are compelling reasons to seek alternative designs, current generic container designs which are compatible with existing stores' infrastructure and, so far as can be anticipated, within future disposal facilities should be adopted. Alternative designs, with significantly different handling and stacking requirements, should be agreed on a UK-wide basis. Relevant to planned stores or stores which may accept new package designs in the future.	3.2
9	Package materials. The package materials standardised waste containers broadly include stainless steel, reinforced concrete and ductile cast iron. Where alternative materials are considered these should be incorporated into the proposed UK's Long-term Monitoring Programme, or similar arrangement, at the earliest opportunity to establish a credible baseline to inform decision making. Relevant to planned storage systems considering materials and/or environmental conditions for which there is limited operational experience.	3.2; 6.5
10	Maintaining transportability. Awareness should be provided and then maintained between the storage safety case and future transport requirements to reduce the risk that packages may not be transportable when required. Most relevant to storage systems comprising of any packages not reliant on a transport container such as a SWTC.	5.1.3

GP	Description	Subsection
11	Package evolutionary processes. Plausible evolutionary processes for all package types during storage should be determined during package design and a recorded assessment made of the significance to the package safety functions. Package performance criteria should be derived for all package types. Relevant to all waste packages and should be applied proportionately according to the categorisation - see [31].	3.1.2
12	Package care and management – controlled. Containers and packages, destined for interim storage, should be subject to appropriate care and management from the earliest stages of the package lifecycle. This should include setting appropriate store WAC to prescribe an effective approach. Relevant to all waste packages and any storage system which may receive additional packages.	3.4
13	Package care and management – uncontrolled. If containers or packages are temporarily outside of a controlled environment then they should be covered, including the base, to protect them. Especially relevant if containers or packages may be 'buffered stored', and during transfer or transport.	3.4
14	Local planning constraints. The implications of any constraints set by local planning authorities for the removal of packages from a site, e.g. based on the assumed availability of a GDF, and building capacities for storage should be made known to the authority as this may not be practicable to achieve and have considerable UK-wide implications. Relevant to stores being designed and planned.	4.1.2
15	Store design – monitorability. Designs should ensure ease of monitoring package and store life-limiting components. The degree of monitorability required should be proportionate with the risk to future disposability of stored packages. Most relevant to future stores. Any opportunities to improve arrangement for existing stores should be considered - see A3 (Modifications to Existing Stores).	4.1.3
16	Store design – life-limiting components. The life-limiting components should be identified, and claims made for component longevity substantiated. Future stores should be constructed with a minimum design lifetime of 100 years. Relevant to all stores and stages of the lifecycle.	4.2.2

GP	Description	Subsection
17	Store design – environmental controls. Store design – environmental controls. A robust approach, particularly in the case of stainless steel packages, should minimise the ingress of airborne salts by filtering the inlet air and keeping external doors closed when not in use. Cycling of surface wetting and drying condensation events should be minimised. Relevant to all stores, especially those with packages and life-limiting features liable to localised corrosion.	4.3.1, 4.4.2
18	Store design – contaminants. The chemical composition of potential contaminant deposition, in the locality of the store, and within the store before it is actively commissioned should be assessed to inform the setting of OLCs. Relevant to all stores, especially those with packages and life-limiting features liable to localised corrosion.	4.3, 4.4.1, 4.4.2
19	Operational limits and conditions. Operational Limits and Conditions (OLCs) should, as a minimum, be prescribed for RH, chloride salt deposition and temperature as appropriate to the storage system's context. The environmental approach/controls should be optimised to meet the set OLCs, and compliance with the OLCs monitored. Any excursion outside the target ranges should be recorded and the reasons for it investigated (see GP 22 – Package/Store Sentencing Group). Relevant to all stores, especially those with packages and life-limiting features liable to localised corrosion.	3.3, 4.4.1
20	Import contaminant checks. Import contaminant checks. At import, packages should be appropriately checked to ensure that contamination levels are consistent with the store's environmental control approach and WAC. Relevant to storage systems still to receive waste packages, and storage systems with materials sensitive to contaminant deposition	5.1.1
21	Minimising movements – opportunities. Any necessary package movements, which are not already planned for inspections, should be exploited as a monitoring and/or inspection opportunity where practicable and appropriate. Conversely, movements for planned inspections should be exploited, where appropriate, for the others drivers considered. Most relevant to storage systems with constrained package movements, e.g. with non-contact handleable packages, and with high-category packages [31].	5.1.3

GP	Description	Subsection
22	Package sentencing groups. A packaging sentencing group should be established to advise on suitable actions to take concerning package performance issues across the lifecycle [92].]The group should comprise of SQEP, and during operations may also be involved in product quality issues arising during packaging, setting WAC, and import surveillance. Relevant to all storage systems, especially those with a high rate of import and with high-category packages [31].	5.3.3
23	Maintaining contingency space. Where it cannot be achieved through additional on-site storage capability, a proportionate 'contingency' space should be established so that any future requirement to alter package configurations can be achieved practicably and flexibly. This should include the ability to manage a proportionate number of overpacked packages. Relevant to all storage systems, especially those without additional on-site storage capacity and with high-category packages [31].	5.3.3
24	Maintaining intervention plans. Credible contingency plans for the possibility of requiring intervention to maintain package safety functions should be established in addition to a package quality management system. This may include consideration of changes to the store environmental controls. Relevant to all storage systems, especially those with high-category packages [31] and where there is a high dependency on the environmental controls.	5.3.3; 5.4
25	Access to rework facilities. Consideration should be given to providing access to rework facilities, which may be at a site or regional level. Facilities should have the potential capability to deal with plausible reworking requirements. Overpacking may be adopted as an approach of rework for unshielded packages. Especially relevant to storage systems, with high-category packages [31].	5.3

GP	Description	Subsection
26	Extending store operational lives. The replacement and refurbishment requirements should be established together with any proposed enhanced operating and maintenance regimes to extend current store operating lives, with safety as an overriding priority as well as maintaining and maintain the disposability of waste packages. Schedules for appropriate maintenance, refurbishment and replacement of store structures, plant and equipment need to be underpinned and clearly identified on asset management programmes. Relevant to all storage systems, especially older stores where designed before current waste strategies were established.	5.5
27	Establishing system baselines. The baseline condition of store life-limiting components, the store environment, and the waste packages (ideally related directly to all relevant safety related functions and through manufacturing specifications) should be established at appropriate times. Information should be recorded and shared strategically. Relevant to all storage systems. However, for existing stores the practicability of establishing the baseline conditions may be both low (for non-contact handleable packages), and of lower potential value.	6.1
28	Recording system performance. The performance of the storage system should be recorded and shared on a regular basis with other store operators to ensure maximum learning. Information recorded should include deposition rates and composition of salts (which may be directly measured, or appropriately inferred from appropriate sources) and note any correlation with package performance and impact on store life-limiting components. Relevant to all storage systems following construction.	6.2
29	Monitoring inspection rates. A target rate of monitoring and inspection, to provide desired confidence over interim storage conditions, should be established. This is derived from the risk analysis and sampling strategy. Cost benefit analysis should be used to justify the actual rate proposed and the approach agreed with stakeholders. Relevant to all storage systems.	6.3
30	Maintaining an archive. A strategic archive of equipment, spares and materials to inform future decision making should be established. The inventory should be recorded and updated regularly Relevant to all storage systems noting the opportunity for stores of similar design and those on a common site to share this resource, in addition to any UK-wide approach.	6.4

GP	Description	Subsection
31	Deployment of inactive samples and dummy packages. An optimum number of samples should be established for each store, proportionate to risk to disposability monitoring/inspection benefits afforded, and any unique features or properties of packages in the store. Relevant to all storage systems especially those with non-contact handleable packages and high-category packages [31].	6.5.1

8. UK Stores List

Status	Store Name	Description
	AWE (Aldermaston)	
	HAW Stores 1-4	Contains predominately plutonium and uranium contaminated material packaged in 200 litre drums pending future conditioning.
	DSRL (Dounreay)	
	Dounreay Cementation Plant (DCP) Interim Drum Store (IDS), Store Extension (SE) and Store Extension 2 (SE2).	Contains immobilised raffinates in 500 litre packages. Overpacked RHILW is also stored pending conditioning. Second store extension (SE2) is under construction.
	Unshielded Waste Store	Proposed modification to an existing LLW store at Dounreay for storage of shielded ILW packages including 6m^3 concrete boxes, TRU-Shield® packages (316L on the outer and inner liner with 2" lead walls) and 500 litre packages.
	SL (Sellafield)	
	Box Encapsulation Plant Product Store (BEPPS) 1	For 3m^3 packages and 500 litre packages in stillages.
	BEPPS 2	For 3m^3 packages and 500 litre packages in stillages.
	BEPPS 3-4	For 3m^3 packages and 500 litre packages in stillages.
	Lightly Shielded Store 1 (LSS1)	For lower hazard decommissioning and operations packages. Designs progressing.
	Lightly Shielded Store 2 (LSS2)	As for LSS1, option to extend storage capacity during 2030s.
	Engineered Drum Store 1 (EDS1)	Contains plutonium contaminated material (PCM) packages.
	EDS2	Contains PCM packages.

Status	Store Name	Description
	EDS3	Contains PCM packages.
	EDS4-5	For PCM packages.
	Encapsulated Product Store 1 (EPS1)	Contains 500 litre packages in stillages.
	EPS2	Contains 500 litre packages in stillages.
	EPS3	Operational from April 2014. Takes 500 litre packages in stillages and $3m^3$ packages.
	Interim Storage Facility 1 (ISF1)	For Self-Shielded Boxes from FGMSP and legacy fuel programmes.
	Miscellaneous Beta Gamma Waste Store (MBGWS)	Existing store containing packages yet to be sentenced as being disposable.
	Vitrified Product Store 1 (VPS 1)	Contains HLW packages.
	VPS 2	To replace VPS1.
	Windscale Advanced Gas-cooled Reactor (WAGR) Store	Contains $6m^3$ concrete boxes (WAGR boxes) and Borderline ILW in HHISOs (Half-Height ISO Containers) /TC05s (Multi Use ISO Skip Containers).
	Waste Packaging and Encapsulation Plant (WPEP) Store	Contains immobilised waste from effluent treatment plants in 500 litre packages.
	NRS (multiple sites)	
	ILW Store, Hunterston A	Active since April 2014.
	Interim Storage Facility (ISF), Berkeley	Operational, taking DCICs and $6m^3$ concrete boxes. Also taking DCICs from Oldbury.
	ISF, Bradwell	Operational, currently taking DCICs from Dungeness A and in the future from Sizewell A. Contains all Bradwell waste.
	ISF, Chapelcross	Commissioning completed. Store will take DCIC packages, overpacked, sealed 500-litre drums, overpacked TSVs and $6m^3$ concrete boxes.

Status	Store Name	Description
	ISF, Hinkley Point A	Commissioned for 6m^3 concrete boxes, will also take DCICs and 3m^3 boxes.
	ISF, Wylfa	Existing Temporary Storage Facility operational. Small ISF planned for longer-term interim storage
	ILW Store, Trawsfynydd	Contains stillages with '1803-type' drums of resin wastes, concrete-overpacked 3m^3 boxes and 3m^3 drums
	Harwell ILW Box Store - HIBS	Commissioning complete. Will take 6m^3 concrete boxes of decommissioning wastes. Will also take 6m^3 concrete boxes from Winfrith.
	Harwell Vault Store	Contains 500 litre packages.
	Winfrith Treated Radwaste Store (TRS)	Contains 500 litre packages of encapsulated sludge from SGHWR – Packages reclassified as LLW and disposed of at LLWR.
	EDF Energy (multiple sites	
	Sizewell B Store	Contains waste which is awaiting agreement and implementation of packaging proposals.
	AGR Sites (Dungeness B, Heysham 1 & 2, Torness, Hartlepool)	Proposed store at each site for packages of resin and sludge wastes; detailed packaging proposals to be agreed.
	AGR Sites (Hunterston B & Hinkley Point B)	Proposal to share NRS ISFs on respective sites.

	Key (as of 2025)
	Operational store
	Under development
	Future or planned store

9. Glossary

approach	a process or method described in the Guidance to assist Store Operators in selecting appropriate tools or options, and/or take appropriate actions according to the context of their storage system.
asset management	an approach to ensure that an asset, such as a waste Store, is managed to ensure satisfactory operation through to final disposal of packages or decommissioning.
baselining	measurements of safety related aspects of the storage system, usually taken at the beginning of major lifecycle events, against which ongoing monitoring and inspection results can be compared.
broad front decommissioning	Undertaking decommissioning activities across many facilities or plant areas at once, rather than focussing on a single structure. It reflects a large-scale, multi-facility effort to progress decommissioning in parallel across the site.
buffer storage	short-term storage of containerised raw waste as a precursor to its conditioning, or short-term storage of packaged waste pending import into a store.
cold handling	cold handling, also known as inactive commissioning, involves testing the store infrastructure before any radioactive waste packages have been imported, consistent with engineering norms
conditioned	waste that has been placed in a waste container and any other measures taken to produce a satisfactory wasteform that fulfils disposal requirements, for example, immobilisation or drying.
corrosion coupons	retrievable test pieces of container material or life-limiting components placed in stores from which the likely surface conditions of the container or life-limiting components can be inferred through surrogate measurements. Coupons can also be embedded within packages to measure internal corrosion rates.
decay storage	the process of allowing material containing short-lived radionuclides to decay so that the final waste is easier to dispose of as radioactive waste, or until the point where the waste becomes can be managed as a lower waste category or exempt from radioactive substances legislation.
disposable	a waste package that complies with requirements for transport and disposal.

disposal	emplacement of waste in an appropriate facility without the intention of retrieval. See also retrievability, and reversibility.
dissolution	a process whereby waste is dissolved in order that the radioactive material can be subsequently recovered as a smaller volume of material.
dummy package	non-radioactive full scale packages that are demonstrably representative of active waste packages as produced.
environmental monitoring	measurements of levels and chemical form of chloride, temperature and relative humidity at appropriate positions throughout the store. Measurements of particulates and pollutants, and gases from packages may also be appropriate.
finishing facility	any process required following a period of interim storage to ensure an interim product is made disposable.
gas generation	corrosion, degradation of organic materials and radiolysis are the principal mechanisms by which gas can be formed from radioactive waste packages. The generated gas may include radioactive gases such as tritium, ^{14}C gases and radon, as well as bulk inactive gas (e.g. hydrogen and methane).
gas migration	the movement of gas (e.g. advective or diffusive) through the wasteform and engineered vents into the store environment.
good practice	highlighted recommendations to Store Operators presented in the Industry Guidance based on the findings arising from the IPT's work programme.
Higher Activity Waste	HAW includes high level waste, intermediate level waste, and some low level waste unsuitable for prompt disposal at the LLW Repository. This term is typically no longer used in policy and technical documents.
hazard	the potential for harm; disposition to cause detriment.
High Level Waste	waste in which the temperature may rise significantly because of their radioactivity, so that this factor must be considered in designing storage or disposal facilities. IAEA guidance is that thermal power >2 kW/m^3
interim product	A waste package that, in its proposed state for storage, may not be considered directly disposable, but is expected to undergo additional conditioning or finishing to enable disposal.
Intermediate Level Waste	waste with radioactivity levels exceeding the upper boundaries for low level wastes, but which do not require heating to be considered in the design of storage or disposal facilities. IAEA guidance is that ILW thermal power is below ~2 kW/m^3.

immobilisation	Reduction in the potential for the migration or dispersion of the radioactivity and hazardous materials present in a waste.
inactive samples	these are non-radioactive components or simulants of packages that are demonstrably representative of one or more aspect of an active package. They may be maintained either within the store, or elsewhere under known conditions.
inspection	the examination, or measurement, of the properties of a waste package to obtain data which are used to assess the extent of any degradation processes, potentially including any degree of damage that has occurred.
knowledge management	a coherent set of activities to support analysis, prioritisation and continuity of explicit knowledge (information) and tacit knowledge (held by individuals). It also includes the competence of current and future staff to operate and maintain storage facilities as well as the development of new knowledge.
licence condition	a condition attached to a licence issued under the Nuclear Installations Act 1965.
Low Level Waste	radioactive waste having a radioactive content not exceeding 4 GBq/te of alpha or 12 GBq/te beta/gamma activity.
monitoring	continuous or periodic observations and measurements to determine changes in the physical condition of a waste package over time.
near surface disposal/ storage	disposal or storage in a facility which is at the surface of the ground or at depths down to several tens of metres below the surface.
Overpack	a secondary (or additional) outer container for one or more waste packages, used for handling, transport, storage and/or disposal.
package evolution	chemical and physical changes of the package components over time that affects the package performance.
package expansion	Gross or localised package expansion which may be caused by expansive corrosion products, some waste degradation products and formation of certain cement phases.
packaging	preparation of radioactive waste for safe handling, transport, storage and/or disposal by means of enclosing it in a suitable container.
package performance criteria	measurable safety related package features and evolutionary processes that when integrated define the status of the stored package, in addition to requirements for transport and disposal.

passively safe	the provision and maintenance of safety functions which minimise the need for active safety systems, monitoring or prompt human intervention.
periodic safety review	a systematic reassessment of the safety of an existing facility (or activity) carried out at regular intervals to deal with the cumulative effects of ageing, modifications, operating experience, technical developments and siting aspects, and aimed at ensuring a high level of safety throughout the service life of the facility (or activity).
radioactive waste management case	the purpose of a RWMC is to provide a transparent demonstration of how the key elements of long-term safety and environmental performance will be delivered for the management of the waste stream or streams covered. This should cover the period from their generation through their conditioning, storage and to their removal from site for eventual disposal.
raw waste	waste in its original untreated, unpackaged and bulk form.
retrievability	a characteristic of the design of the waste package and/or the storage/disposal facility that facilitates recovery of waste after emplacement.
reversibility	the capability for a process to be reversed. An example would be the ability of withdrawing wastes from a storage/disposal facility where they have previously been emplaced.
rework	any process involving physical intervention of packaged waste arising from deviation from the planned storage, treatment, or intended disposal process for that packaged waste to restore safety functions. Excluded 'finishing' work.
	Repackage - a type of rework that involves placing the original wasteform into a new container or the original (repaired) container if still suitable.
	Recondition - a type of rework that involves additional processing of the original wasteform.
safety case	a collection of arguments and evidence in support of the safety of a facility or activity
shielded store	a facility which provides a substantial barrier to reduce direct radiation dose rate outside the facility.
simulant package	non-radioactive reduced scale package representative of either specific or generic features of active waste packages.
simulant wasteform	non-radioactive materials developed to be representative of some or all of the chemical and/or physical properties of the anticipated / actual wasteforms.

smart coupons	corrosion coupons with sensors to provide a wireless and real time measurement of local humidity, temperature and salt deposition.
stillage	a frame designed to hold multiple packages so that they can be handled and stacked as a single unit.
storage	placing waste in a suitable facility with the intent to retrieve it at a later date.
	interim storage - storage of waste packages within a purpose built facility, which aims to maximise the lifetime of waste packages, where there is the **planned intention** for a final management step, e.g. transport / transfer of the packages to a licensed disposal facility. Storage will typically be up to about 100 years.
	long-term storage - storage of waste packages within a purpose built facility, which aims to maximise the lifetime of waste packages, pending a defined endpoint. Storage will typically be for at least 100 years and potentially considerably more.
	waste storage system - a multiple-barrier system comprising the wasteform; the waste container; the store environment; and the store structure.
Store Operator	is taken to mean all those in a licensee with direct responsibility for managing the storage system across any part of its lifecycle, including: design and planning, construction, commissioning, import of packages, care & maintenance, export of packages, and decommissioning of the storage facility. Notably, it is taken to include those responsible for store safety cases, and technical support.
toolkits	a list of potential techniques, solutions or other options which have been derived from a collective of operational experience and R&D. When applied, with a suitable approach, context specific tools may be identified.
tools	practicable techniques which may be used to manage one or more aspect of interim storage and which are relevant to the particular storage system's context.
transport container	a reusable container into which waste packages (raw or conditioned) are placed for transport, the whole then qualifying as a Transport Package under the IAEA Transport Regulations. Some waste packages are also transport packages.
transport package	the complete assembly of the radioactive material and its outer packaging, as presented for transport.

	Type B transport package - a type of transport package defined by the requirements in the IAEA Transport Regulations.
	Industrial package - a type of transport package defined by IAEA Transport Regulations. Industrial Packages may be classified as Type 1 (IP-1), Type 2 (IP-2) or Type 3 (IP-3). Industrial Packages are restricted to the carriage of Low Specific Activity and/or Surface Contaminated Object material.
treatment	operations to change the characteristics of the waste. Three basic treatment objectives are: volume reduction, removal of radionuclides from the waste and change of composition.
trigger levels	graded package performance thresholds, described using suitable measurable indicators, which define when intervention may be required by the Store Operator to preserve storage system functionality.
unshielded store	a facility where the package and any over-packs provide an adequate barrier to direct radiation dose rate outside the facility. Typically packages, in their over-pack as appropriate, can be handled without the need for remote handling within the facility.
waste acceptance criteria	these are the facility specific criteria that waste packages must meet to be acceptable into the facility without requiring package specific substantiation of its properties. The waste acceptance criteria should include consideration of future disposal requirements or planned management strategies and provides controls to adhere to the relevant safety cases, e.g. store and transport.
waste container	the vessel into which the wasteform is formed for handling, transport, shielding, storage and/or eventual disposal; also the outer barrier protecting the waste from external intrusions. The waste container is a component of the waste package.
waste package	the wasteform and any container(s) and internal barriers (e.g. absorbing materials and liner), as prepared in accordance with requirements for handling, transport, storage and/or disposal.
	out-of-specification waste package - waste packages, or their safety related components, that exhibit or are reasonably believed to exhibit properties that fall outside the specified range, as endorsed by RWM as part of the disposability assessment process or the store's WAC.
	non-conforming package - waste packages, or their safety related components, that exhibit or are reasonably believed to exhibit performance that is likely to fall outside the eventual WAC for a GDF.

waste storage system	comprises the conditioned wasteform, the waste container, the store environment and the store structure components and the interactions between the components.
wasteform	waste in the physical and chemical form in which it will be stored/disposed. This can include any conditioning media and container furniture, i.e. in-drum mixing devices, dewatering tubes etc, but not including the waste container(s) itself.

Abbreviations and Acronyms

304L	Austenitic stainless steel grade (BS EN 1.4307)
316L	Austenitic stainless steel grade (BS EN 1.4404)
2205	Duplex stainless steel grade (BS EN 1.4462)
AMP	Ageing Management Programme
A*n*	Approach n
AGR	Advanced Gas-cooled Reactor
ALARP	As Low As is Reasonably Practicable
AWE	Atomic Weapons Establishment
BAT	Best Available Technique
BEPPS	Box Encapsulation Plant Product Store
BPM	Best Practicable Means
CDM	Construction Design and Management Regulations
CFD	Computational Fluid Dynamics
CM&I	Condition Monitoring and Inspection
CNS	Civil Nuclear Security (see also ONR)
CoRWM	Committee on Radioactive Waste Management
DCIC	Ductile Cast Iron Container
DCP	Dounreay Cementation Plant
DRP	NDA's Direct Research Portfolio
DSRL	Dounreay Sites Restoration Limited
DSSC	Disposal System Safety Case
EA	Environment Agency
EASR	Environmental Authorisations (Scotland) Regulations 2018

EDF	EDF Energy
EDS	Engineered Drum Store
EPR	The Environmental Permitting (England and Wales) Regulations 2010
EPS	Encapsulated Product Store
FGMSP	First Generation Magnox Storage Pond
FMEA	Failure Modes and Effects Analysis
GDF	Geological Disposal Facility
GGBFS	Ground Granulated Blast Furnace Slag
GP	Good Practice
GSR	General Safety Requirements
HAW	Higher Activity Waste
HF	Human Factors
HHISO	Half-Height ISO Container
HLW	High Level Waste
HSW	Health and Safety at Work etc Act 1974
HVAC	Heating, Ventilating, and Air Conditioning
IAEA	International Atomic Energy Agency (a United Nations agency)
ILW	Intermediate Level Waste
IP	Industrial Package
IPT	Integrated Project Team
IRR17	Ionising Radiations Regulations 2017
ISF	Interim Storage Facility
IWMTOG	Integrated Waste Management Theme Overview Group
IWS	Integrated Waste Strategy
LAW	Lower Activity Waste

LLW	Low Level Waste
LoC	Letter of Compliance
MAGGAS	MAGnox GAS Generation
MBGWS	Miscellaneous Beta Gamma Waste Store
MIC	Microbiologically influenced Corrosion
MoD	Ministry of Defence
MRWS	Managing Radioactive Waste Safely
NDA	Nuclear Decommissioning Authority
NIA65	Nuclear Installations Act 1965 as amended
NISR 2003	The Nuclear Industries Security Regulations 2003
NORMS	National Objectives Requirements Model Standards
NRS	Nuclear Restoration Services
NRW	Natural Resources Wales
NWDRF	Nuclear Waste and Decommissioning Research Forum
OLC	Operational Limits and Conditions
ONR	Office for Nuclear Regulation
OPC	Ordinary Portland Cement
PAS	Publicly Available Specification
PCM	Plutonium Contaminated Material
PETF	Product Evaluation Task Force
PFA	Pulverised Fuel Ash
PPE	Personal Protective Equipment
RH	Relative Humidity
RHILW	Remote–handled Intermediate Level Waste
RMT	Radioactive Materials Transport (see also ONR)

RSA93	Radioactive Substances Act 1993
RWMC	Radioactive Waste Management Case
RWM	Radioactive Waste Management
SAPs	Safety Assessment Principles
SCC	Stress Corrosion Cracking
SEPA	Scottish Environment Protection Agency
SL	Sellafield Limited
SLC	Site Licence Company
SRL	Safety Reference Levels
SOF	Store Operations Forum
SQEP	Suitably Qualified and Experienced Person
SWTC	Standard Waste Transport Container
TAG	Technical Assessment Guide
TC05	Multi Use ISO Skip Container
TCSC	Transport Container Standardisation Committee
TRL	Technical Readiness Level
TRS	Treated Radwaste Store
VPS	Vitrified Product Store
WAC	Waste Acceptance Criteria
WAGR	Windscale Advanced Gas–cooled Reactor
WENRA	Western European Nuclear Regulators' Association
WPS	Waste Package Specification

References

1. NDA, *UK Radioactive Higher Activity Waste Storage Review*, Issue 1, March 2009.
2. Committee on Radioactive Waste Management, *Managing our Radioactive Waste Safely. CoRWM's Recommendation to Government*, CoRWM Doc 700, July 2006.
3. BEIS, *Implementing Geological Disposal – Working with Communities, An updated framework for the long-term management of higher activity radioactive waste*, December 2018.
4. UK Government and Devolved Administrations, *UK policy framework for managing radioactive substances and nuclear decommissioning,* May 2024.
5. Scottish Government, *Scotland's Higher Activity Radioactive Waste Policy 2011*, January 2011.
6. Scottish Government, *Higher Activity Waste Implementation Strategy*, 15 December 2016.
7. Committee on Radioactive Waste Management, *Interim Storage of Higher Activity Wastes and the Management of Spent Fuels, Plutonium and Uranium*, CoRWM Doc 2500, March 2009.
8. UK Government and Devolved Administration, *Response to the Committee on Radioactive Waste Management (CoRWM) Report on 'Interim Storage of Higher Activity Wastes and the Management of Spent Fuels, Plutonium and Uranium*, July 2009.
9. Committee on Radioactive Waste Management, *Ninth Annual Report 2012-13*, CoRWM Doc 3107, June 2013.
10. NDA, *Group Strategy*, Effective from March 2026.
11. NDA, *Integrated Waste Management Strategy Radioactive Waste Strategy*, September 2019.
12. IAEA, *Predisposal Management of Radioactive Waste*, General Safety Requirements Part 5, 2009.
13. IAEA, *Regulations for the Safe Transport of Radioactive Material,* SSR-6, Rev 1, 2018.
14. IAEA, *Methodology for a Safety Case of a Dual Purpose Cask for Storage and Transport of Spent Fuel*, IAEA-TECDOC-1938, 2020.
15. IAEA, *Storage of Radioactive Waste*, WS-G-6.1, 2006
16. IAEA, *Leadership, Management and Culture for Safety in Radioactive Waste Management*, GSG-16, 2022
17. IAEA, *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*, INFCIRC/546, December 1997.
18. IAEA, *Safety Assessment for Facilities and Activities*, General Safety Requirements Part 4, Rev. 1, 2016.
19. IAEA, *Decommissioning of Facilities*, General Safety Requirements Part 6, Rev. 1, 2014.
20. IAEA, Seismic Hazards in Site Evaluation for Nuclear Installations SSG-9, Rev. 1, 2022.
21. IAEA, Site Evaluation for Nuclear Installations, SSR-1, 2019.

22. IAEA, *Interim Storage of Radioactive Waste Packages*, Technical Reports Series No. 390, 1998.
23. WENRA, *Waste and Spent Fuel Storage Safety Reference Levels Reports*, Version 2.3, January 2024.
24. The Stationery Office, *Nuclear Installations Act 1965*, 1965.
25. The Stationery Office, *Health and Safety at Work etc Act 1974*, 1974.
26. *The Environmental Authorisations (Scotland) Regulations 2018*, Scottish Statutory Instruments, 2018, No. 219.
27. The Stationery Office, *Environmental Permitting (England and Wales) Regulations 2016,* 2016.
28. The Stationery Office, *The Environmental Permitting (England and Wales) (Amendment) Regulations 2018*, No. 0000, 2018.
29. The Stationery Office, *The Ionising Radiations Regulations*, 2017 (S.I. 2017/1075).
30. Stationary Office, *Nuclear Industry Security Regulations 2003*, Version 4.1, 2013.
31. Office for Nuclear Regulation, the Environment Agency, Natural Resources Wales and the Scottish Environment Protection Agency, *The management of higher activity radioactive waste on nuclear licensed sites: Joint guidance from the Office of Nuclear Regulation, the Environment Agency, the Scottish Environment Protection Agency and Natural Resources Wales to nuclear licensees*, Revision 2.1, July 2021.
32. Office for Nuclear Regulation, *Safety Assessment Principles (2014 Edition)*, Revision 1, January 2020.
33. Environment Agency, *Radioactive Substances Regulation — Environmental Principles*, April 2010.
34. Environment Agency, *Radioactive Substances Regulation (RSR): objective and principles,* December 2021.
35. ONR and SEPA, *Inspection of RWM's disposability assessment process for the management of HAW in Scotland*, September 2017.
36. NDA, *Geological Disposal — Generic Waste Package Specification Part B: Technical Specification*, DSSC/402/01, December 2016.
37. NWS, *Specification for Waste Packages Containing Low Heat Generating Waste: Part C – Fundamental Requirements,* WPS/220/01, March 2020.
38. NWS, *Specification for Waste Packages Containing Low Heat Generating Waste: Part D – Container Specific Requirements,* WPS/300/05, November 2022.
39. NWS, *Assuring the Disposability of Waste Packages for Geological Disposal*, WPG/MAN/01, February 2025.
40. NWS, *Disposability Assessment for HAW*, WPG/MAN/02, October 2025.
41. RWM, *Upstream Optioneering: Summary of LLW/ILW Opportunities*. NDA Report no. NDA/RWM/134, August 2015.
42. National Nuclear Laboratory, *Proposed Methodology to Assess Performance of ILW Waste Packages*, NNL(10)10732, Issue 2, February 2012.
43. Risktec Solutions Limited, *Detailed HF/HP Guidance — Interim Storage of HAW Packages*, Issue 3, September 2011.

44. UK Health and Safety Executive, *Reducing Error and Influencing Behaviour*, HSG48 2nd Edition, 1999.

45. NDA, *The NDA group Sustainability Strategy* 2022, 2022.

46. NDA, *The NDA Value Framework*, August 2021.

47. NDA, *Sustainability in Business Cases*, OPIM01-G01, 2023.

48. NDA, *Optimisation of Future Waste Store*, April 2024

49. BREEAM UK, *Technical Manual SD5078: BREEAM UK New Construction*, 2018 3.0

50. BREEAM UK, *Technical Manual SD216 Refurbishment and Fit-out*, 2014 2.0

51. National Nuclear Laboratory, Recommendations for Performance Levels for Waste Package Identification Markings, NNL(10)11221, Issue 2, January 2011.

52. NDA, Requirements Framework for Managing Information Relating to Radioactive Waste on Nuclear Decommissioning Authority Sites, 13006659, August 2010.

53. RWM, *Geological Disposal – Package Evolution Status Report*, Issue 2, DSSC/451/02, 2016.

54. NWS, *Selection of Packaging Approach for Low Heat Generating Waste*, WPG/MAN/03, December 2025.

55. NWS, *Guidance on the Design of Containers for Low Heat Generating Waste*, WPG/CON/01, January 2026.

56. NWS, *Performance Delivered by the Waste Package for Low Heat Generating Waste*, WPG/PAP/01, March 2026.

57. Nirex, *Corrosion Resistance of Stainless Steel Radioactive Waste Packages*, report N/110, 2004.

58. Quintessa, *Corrosion Resistance of Austenitic and Duplex Stainless Steels in Environments Related to the Nuclear Decommissioning Authority's Phased Geological Repository Concept*, QRS-1384C-R1, November 2007.

59. AMEC, *The Atmospheric Corrosion of Ductile Cast Iron*, 17391-TR-003, Issue 3.2, July 2012.

60. C. Padovani, O.E. Albores-Silva, and E.A. Charles (2015). *Corrosion Control of Stainless Steels in Indoor Atmospheres—Laboratory Measurements Under MgCl2 Deposits at Constant Relative Humidity (Part 1).* Corrosion Science 71, No. 3, 292-304.

61. C. Padovani, R.J. Winsley, N.R. Smart, P.A.H. Fennell, C. Harris, and K. Christie (2015). *Corrosion Control of Stainless Steels in Indoor Atmospheres—Practical Experience (Part 2).* Corrosion Science 71, No. 5, 646-666.

62. Waste Management Technology for NDA-RWMD, *Review of Wasteform Ageing — Up to Repository Resaturation, Parts 1 and 2*, WMT(06)P118 and WMT(07)P052, September 2010.

63. Serco, *The Effect of Drum Movements on Internal Corrosion Rates 2006/2007*, SA/SIT/18962/C001 Issue 1, May 2008.

64. B.T. Swift and S.A. Watson, *The Development of a Calculational Method for the Estimation of Gas Generation Rates from Cement Encapsulated Wastes: Part 18 Overview of the MAGGAS Model*, NRS reference MES/EST/MIMP/REP/0096/12 Issue 2, December 2024.

65. National Nuclear Laboratory, *Calculation of Metal Corrosion Rates in Grouted ILW Packages*, NNL (10) 11220 Issue 2, March 2011.
66. A.R. Hoch, M. Wilkes*, Modelling the Expansion and Cracking of Grouted Wasteforms Containing Mild Steel or Magnox*, AMEC/002053/001 Issue 2, 2016.
67. RWM, *The Atmospheric Corrosion of Stainless Steel in Stores (ACSIS) Model*, RWMD/03/003, December 2016.
68. Magnox North and South, *Guidance for Care and Management of ILW Packages*, MEN/EWST/GEN/REP/0057/08, Issue 1, January 2009.
69. IAEA, *Design Lessons Drawn for the Decommissioning of Nuclear Facilities*, IAEA-TECDOC-1657, 2011.
70. UKAEA, *Higher Activity Waste — Interim Store Performance and Monitoring*, TSG(10)0650, Issue 1, March 2010.
71. NWS, Geological Disposal: Generic Specification for the stillage for the transport and disposal of 500 litre drum waste packages, WPS/605/02, August 2016.
72. ONR, Technical Assessment Guide - Internal Hazards, NS-TAST-GD-014, Issue 7.1, December 2022.
73. ONR, *Technical Assessment Guide - External Hazards*, NS-TAST-GD-013, Issue 9, October 2023.
74. The Stationery Office, *The Construction (Design and Management) Regulations 2015*, SI No 51, 2015.
75. IAEA, *Decommissioning Facilities Using Radioactive Material, Safety Requirements No. WS-R-5*, 2006.
76. Office for Nuclear Regulation, *Security Assessment Principles for the Civil Nuclear Industry*, Version 1, 2022.
77. Nuclear Ventilation Forum, *An Aid to the Design of Ventilation of Radioactive Areas, NVF/DG001*, January 2009.
78. NDA, *Optimisation of Future Waste Stores*, Issue 1, April 2024.
79. Kumaran, M.K., Mitalas, G.P. and Bomberg, M.T., *Fundamentals of Transport and Storage of Moisture in Building Materials and Components*, in Trechsel, H.R. (Ed.) Moisture Control in Buildings, ASTM MNL 18, 3-17, 1994.
80. Serco, *4 Metre Box Monitoring Programme — Final Report for the Period 2007-2010, report to RWMD SERCO/TCS/006028.01/Issue001*, February 2011.
81. C. Leygraf and T. Graedel, *Atmospheric Corrosion, Electrochemical Society Series*, Wiley, 2000.
82. AMEC, *The Potential Role of Fungi and Algae in the Atmospheric Corrosion of Waste Packages in Interim Storage*, 17391-TR-005, Issue 3, September 2012.
83. C. Harris, *A survey of environmental conditions in ILW stores and potential GDF analogues*, AMEC report to RWM 17391/TR/0007, 2015.
84. S. Shoji and N. Onaka, *Effects of Relative Humidity and Chloride Type on Stainless Steel Room Temperature Atmospheric Stress Corrosion Cracking*, Corrosion Engineering 38, 1989, 111-119. [Copyright Publication]

85. T. Prosek, A. Iversen, C. Taxen, D. Thierry, *Low temperature stress corrosion cracking of stainless steels in the atmosphere in the presence of chloride deposits*, Corrosion 65 (2), 2009, 105-117.

86. C. Harris, *A survey of environmental conditions in ILW stores and potential GDF analogues*, AMEC report to RWM 17391/TR/0007, April 2015.

87. Lagerblad, B., *Carbon dioxide uptake during concrete life cycle – State of the art, Swedish Cement and Concrete Research Institute Report 2:2005*, ISBN 91-976070-0-2, ISSN 0346-8240, December 2005.

88. NDA, Upstream Optioneering: *Overview and uses of the 6 cubic metre concrete box*, NDA Technical Note 18959097, March 2013.

89. Fuller, F. Neall, M. Ferreira, H. Kuosa, M. Hayes, J. Rashburn, *Review of the Durability of Concretes for ILW Containers and HLW/SF Buffers,* RWM Report RWM/Contr/19/007/2 Version 2, March 2019.

90. UKAEA, *Effects of Store Emplacement Strategies on ILW Package Longevity*, UKAEA/TSG(10)0633, Issue 1, March 2010.

91. Environment Agency, *Reworking Intermediate Level Radioactive Waste*, SC040047, November 2005.

92. NWS, *Guidance on the Sentencing of Non-compliant Waste Packages*, WPG/ARM/04, December 2024.

93. Magnox North, *Reworking and Management of Non-conforming Packages: Applicable to Initially Compliant Packages*, MEN/EWST/GEN/REP/0045/10, Issue 1, May 2011.

94. British Standards Institute, *Asset management*, BS ISO 55000 Series, 2024 (BS ISO 55000:2024, BS ISO 55001:2012, BS ISO 55002:2018).

95. IAEA, *NDA Industry Guidance Interim Storage of Higher Activity Waste Packages: Integrated Approach. Peer Review Final Report,* May 2015.

96. IAEA, *Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants, Specific Safety Guide No. SSG-48,* 2018.

97. HSE, *Managing Ageing Plant - A Summary Guide*, RR823.

98. National Nuclear Laboratory, *Development of a Waste-storage System Baselining Approach*, NNL(12)12303, Issue 1.1, October 2012.

99. National Nuclear Laboratory, *Review of Potential Baselining Technologies,* NNL(12)12317, Issue 1, October 2012.

100. National Nuclear Laboratory, *Development of Innovative Solutions to Monitor Radioactive Waste Packages in Order to Validate Long-term Behaviour and Performance*, NNL(09)10730, Issue 2, March 2010.

101. AMEC, *Characterisation of Environmental Conditions in an ILW Store*, D.005265/001, July 2012.

102. CIRIA, *Intelligent Monitoring of Concrete Structures*, C661, 2008.

103. Babcock, *Development of a Methodology for Determining ILW Package Monitoring and Inspection Requirements*, UKAEA/TSG(10)0723, Issue 1, December 2010.

104. Statutory Instrument, *The Lifting Operations and Lifting Equipment Regulations,* No 2307, 1998.

105. National Nuclear Laboratory, *Long-term Monitoring of Simulant ILW Packages — Technical Stakeholders Report*, Issue 2, March 2010.

106. Hyder Consulting, *Development of an Optimised Approach for Dummy Packages*, WX23458_WP8, Issue 1, March 2010.

107. National Nuclear Laboratory, *Corrosion Test Pieces for Monitoring the Storage of ILW Packages*, NNL(08)9402, Issue 4, May 2009.

108. International Organisation for Standardisation, *Quality management systems – Requirements,* ISO 9001:2015, 2015.

109. NWS, *Assuring the Disposability of Waste Packages for Geological Disposal,* WPG/MAN/01, October 2025.

110. NDA, *Knowledge Management Policy*, IMP05 Rev. 1, March 2013.

111. NDA, *Managing NDA Information Requirements*, IMP06 Version 4.0, April 2019.

112. RWM, *Waste Package Data and Information Recording Requirements: Explanatory Material and Guidance,* WPSGD No. WPS/850/03, December 2015.

113. RWM, *Long-term Management of Information and Records: Explanatory Material and Guidance,* WPSGD No. WPS/870/03, September 2016.

114. IAEA, *Maintenance of Records for Radioactive Waste Disposal*, IAEA-TECDOC-1097, July 1999.

Nuclear Decommissioning Authority
Herdus House, Westlakes Science and Technology Park, Moor Row, Cumbria CA24 3HU

www.nda.gov.uk