



Industry Guidance

**Interim Storage of Higher Activity
Waste Packages – Integrated Approach**

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Foreword

Waste storage is an essential component of the higher activity waste (HAW) management lifecycle and provides a safe, secure environment for waste packages awaiting final disposal. This position is an important aspect of UK Government and Devolved administrations' radioactive waste management policies, with the overarching approach to storage set out in NDA Strategy and the NDA Radioactive Waste Strategy. Storage systems can also provide a safe and secure environment for waste packages awaiting further conditioning.

A system of robust storage arrangements provides high confidence that packages will be disposable at the end of the storage period and will be unaffected by any variance in the availability of disposal routes. NDA will ensure that its strategy continues to support the safe and secure storage of HAW for a period of at least 100 years. The storage system effectively provides containment for the prevention of releases of radioactivity to the outside environment.

In delivering the NDA mission we will continue to generate and package our radioactive waste arisings over many decades. Hence, the packaged HAW is of high intrinsic value in terms of environmental, safety and security benefit, as well as cost and programme investment. Enabling and managing an appropriate storage system is a vital part of delivering the mission and ensuring that radioactive waste is suitable for disposal after the storage period.

The Store Operations Forum (SOF) brings together NDA strategic leads, Radioactive Waste Management Ltd (RWM), waste producers and store operators. It is designed to engage, coordinate and drive strategy development through shared learning concerning the storage of containerised HAW across the UK prior to disposal and ensuring that this HAW 'Industry Guidance' document represents good practice.

The Guidance has been used successfully since its launch in 2012. Its most recent update (Issue 4) includes an Approach to safe containerised storage pending future treatment. This Approach includes both decay storage and storage of interim products. It also formalises Asset Management as a defined Good Practice.

It is expected that SLCs 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. In future, the SOF will be devising new approaches to this guidance to allow targeted updates regarding specific topics where industry approaches are being developed and refined. If you have any comments on the Guidance, please email these to **strategy@nda.gov.uk**.

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March 2021

Abstract

A cross-industry team assembled by the NDA has developed this Industry Guidance on the interim storage of packaged higher activity waste (HAW). 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. The latest revision, Issue 4 includes considerations relative to safe containerised storage pending future treatment, including a new dedicated Approach A4).

It is intended that the Guidance will be used by those involved in managing any aspect of current and future UK stores for packaged HAW. An additional companion document describes how the Guidance aligns with UK policies on HAW management.

The Guidance seeks to cover the main significant technical issues currently identified from interim storage of packaged HAW, 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 HAW, the Guidance describes six common principles and 28 specific approaches covering the lifecycle of interim storage and variation in HAW 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) 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 Welsh Government has also decided to adopt a policy for geological disposal for the long term management of HAW [4].

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 [3]. The NDA is constructing a new baseline for HAW management at its sites in Scotland that assumes that HAW will be stored on the site at which it arises for a period of approximately 300 years, with stores being maintained, refurbished or replaced as appropriate throughout the storage period [6]. There is no HAW 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 NDA should implement greater UK-wide strategic co-ordination of the conditioning, packaging and storage of HAW. The U.K. 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 HAW. 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 HAW 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.”

The IPT was dissolved in 2012 and the Store Operations Forum (SOF) inherited the role of monitor and curator of the Guidance. 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).

1.2 Guidance Overview

The Guidance covers the currently recognised technical challenges arising from interim storage, 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 HAW storage, and it describes principles, approaches, good practices, and toolkits as an aid to current and prospective Store Operators.

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 HAW stores, has met 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 HAW storage.

The strategic need to provide adequate HAW storage capacity in the UK was a major topic in the 2009 CoRWM and NDA reports, and is discussed in the NDA's Strategy [10], NDA's HAW Strategy [11], and NDA's HAW Treatment Framework [12]. Work is in hand to consider this provision, in liaison with other organisations, as part of implementing the NDA Strategy [13].

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 3.2;
 - 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 6.3.
- 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 safety case;
 - II. assurance that waste packages remain readily exportable for eventual disposal, finishing (if applicable) or continued storage elsewhere; and
 - III. assurance that licensees will undertake BPEO/ BAT studies for packaging and storage of wastes.

It is important to recognise that all packages that are being considered for disposal in the planned GDF must be accompanied by a comprehensive set of records that document the contents of the package and its previous assurance. RWM, as the ultimate recipient of the packages, has defined its requirements for package records [15]. To avoid duplication, package records are not addressed by this Guidance document.

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 and their Store Operators;
- NWDRF and its working group covering storage, see subsection 2.3.1;
- NDA;
- other owners of HAW; and
- regulators.

1.2.3 Changes since last issue

The following changes, since Issue 3 was published in January 2017, are highlighted:

- Incorporation of interim products throughout the guidance following recommendations from the SOF, including the addition of a new approach; A4, interim products;
- updates to the glossary;
- revising the references to reflect changes since Issue 3.

1.2.4 Future issues

Future issues of the Guidance will be sponsored by the Strategy and Technology Team in NDA's Integrated Waste Management Directorate. The change control process for the Guidance is described in subsection 2.3.3.

1.2.5 Scope

The Guidance covers the interim storage of packaged HAW, 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 HAW packages. Near surface storage may be considered in the future; the Guidance would equally apply.
- 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].

- c) **HAW packages** within surface stores, which are subject to assessment through Radioactive Waste Management Limited's (RWM's) Disposability Assessment process, and which:
- I. have been or are planned to be conditioned, (including interim products, see Approach A4), for disposal or long-term storage; 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 appropriately 'passively safe' to the Regulators.
- d) **HAW packages** mainly comprising short-lived radionuclides that are being stored to take advantage of radioactive decay and keep options open, so that they may subsequently be managed differently, for example, by disposal to the near-surface environment, if they are no longer deemed to be HAW.

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 following waste storage contexts:

- near-surface stores with packages stored below ground level, which may require additional consideration of flood prevention and water ingress; and
- long-term stores for LLW packages.

The Guidance might also have some useful application to stores containing dry spent fuel and nuclear material, and future issues are expected to develop this application further.

Principal exclusions

This Guidance does not cover the following waste storage and long-term management contexts:

- 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 and nuclear materials; 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 essential background:

- a) General Safety Requirements (GSR) Part 5 [14], which establishes the safety requirements that apply to all facilities and activities that are involved in the management of radioactive waste before disposal.
- b) Regulations for the Safe Transport of Radioactive Material (SSR-6) [17], 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.
- c) Storage of Radioactive Waste WS-G-6.1 (2006) [18].
- d) The Management System for the Processing, Handling and Storage of Radioactive Waste GS-G-3.3 (2008) [19].

The IAEA is currently drafting its Safety Standard relating to the Management System for the Pre-Disposal Management and Disposal of Radioactive Waste (DS477) which includes sections on storage and the need for alignment with disposal routes. An extant technical report on interim storage [20], 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) [21] 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 is highlighted:

- Nuclear Installations Act 1965 as amended (NIA 65) [22] and standard conditions applied to nuclear site licences;
- Health and Safety at Work etc. Act 1974 (HASAW) [23];
- in Scotland: the Environmental Authorisations (Scotland) Regulations 2018 (EASR) [24]

- in England and Wales, the radioactive substances regulation form part of the Environmental Permitting Regulations (EPR) 2016 [25], as amended in 2018 [26];
- the Ionising Radiations Regulations 2017 (IRR17) [27]; and
- the Nuclear Industry Security Regulations 2003 (NISR 2003) [28].

1.3.3 Regulatory guidance

The Regulatory 'Joint Guidance' on HAW management [29] 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) [30], and Technical Assessment Guides (TAGs) which cover both new and existing storage facilities; and
- Environment Agency's (EA's) Radioactive Substances Regulation Environmental Principles [31].

The Joint Guidance [29] also states that the Government continues to develop a policy and regulatory framework that aims to ensure that:

- a) radioactive wastes are not unnecessarily created;
- b) such wastes as created are safely and appropriately managed and treated;
- c) 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 [29] 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 maintain and utilise the 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 [29]. It also recommends effective characterisation of waste and segregation of short-lived waste streams, so that decay storage opportunities may be identified. Decay storage is recognised as a management strategy that would underpin arguments not to condition wastes to a passively safe form as soon as is reasonably practicable.

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 Office for Nuclear Regulation (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 [29] from an early stage of planning storage systems to reduce the risk of non-compliance against Regulatory requirements and for consistency with developing cost-effective solutions. See GP1 (Stakeholder engagement).

1.3.4 RWM packaging standards

For HAW, 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 disposability assessment process assesses packages against likely requirements however because 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 HAW 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. The Scottish Environment Protection Agency (SEPA) currently advises that any waste suitable for disposal will also be suitable for long-term storage in accordance with Scottish Government policy.

Waste producers are encouraged to work collaboratively with RWM in the development of a packaging strategy and maintain engagement throughout the process (e.g. use of RWM Expert View process). The Joint Guidance [29] 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.

RWM, 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 within the Generic Waste Package Specification (GWPS). Additionally, RWM has established user level Waste Package Specification and Guidance Documentation (WPSGD) to assist interpretation of these requirements.



It is recommended that Store Operators consult the following documents, and other references contained therein, for further guidance on RWM packaging standards:

- a) The Disposal System Specification Part B – Technical Specification [32] for the high level technical requirements defined by RWM to frame the development of a disposal system solution;
- b) Guidance on the preparation of submissions for the disposability assessment of waste packaging proposals [33] for a description of the disposability assessment process which forms part of the Disposal System Safety Case (DSSC) documentation suite.

The disposability assessment process can be considered a risk reduction process [8]. Following the disposability assessment 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. RWM provides advice on appropriate levels of assessment and endorsement for the packaging of interim products.

The Store Operator 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 with RWM should occur at an early stage of the development of the storage system, and with any emergent disposability issues. See GP1 (Stakeholder GP1 engagement).

2. The Integrated Approach (Approach A0)

2.1 Overview – Overarching Approaches A1 to A4

The relationship of the Guidance compared with the hierarchy of other sources of interim storage information is shown pictorially in Figure 1. This illustrates the intended ‘pitch’ of the Guidance as an interface between national legislation and regulatory guidance, with the operational experience and detailed underpinning provided by R&D. Additionally, it also signifies the important co-relationship between the Licensee’s own tailored arrangements and RWM’s specifications and guidance for a GDF.



Figure 1 Illustrative Strategic Position of the Guidance

The Guidance comprises several elements that, when integrated, seek to achieve the objectives described in subsection 1.2.1. These elements are:

- Principles (A to F), which provide a consistent framework– see subsection 2.1.1;
- Good Practices (GP1 to GP31), which highlight recommendations to store operators – see subsection 2.1.2;
- Approaches (A0 to A28), 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 2.1.3;

- Toolkits (TK1 to TK23), which comprise of a collection of potential techniques, solutions or other options which have been derived from operational experience and R&D – see subsection 2.1.4;
- Tools, which are user selected techniques, solutions or other options that are relevant to a particular storage system’s context and may be identified by application of an approach.

These elements, their derivation and their inter-relationship, are shown pictorially in Figure 2. 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 of Abbreviations and Acronyms and GP2 (Technical terminology).

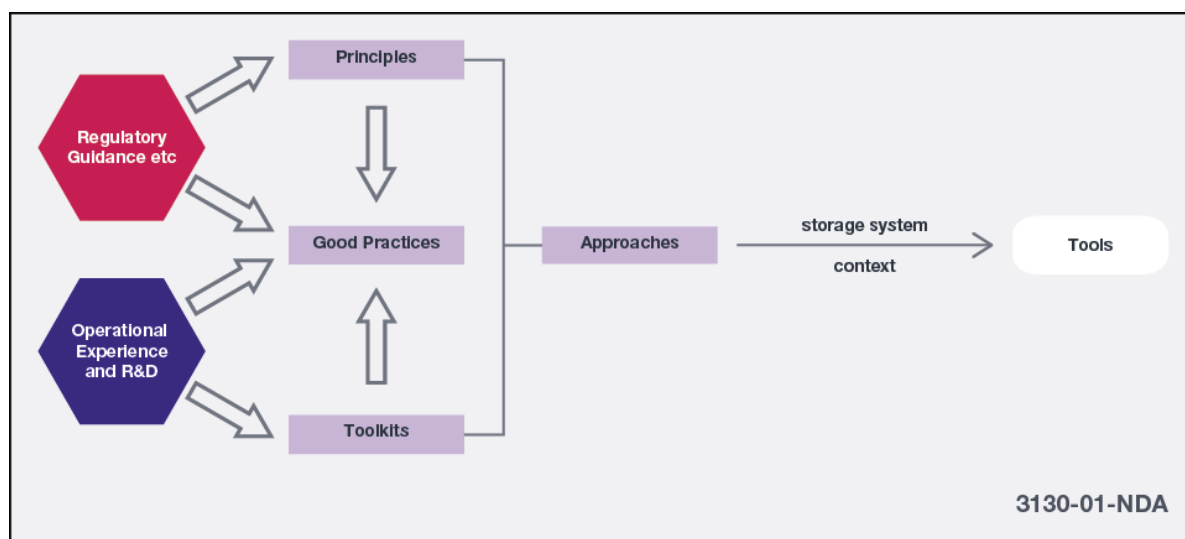


Figure 2 Guidance Elements and their Inter-relationship

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).

2.1.1 Principles

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

- i. Cradle-to-grave lifecycle. Packages should be managed to protect their overall longevity 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 appropriately good store designs with due consideration of the hazards presented by the waste packages and the quality of storage required. The overall storage system, i.e. the wasteform and its container, 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. 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 asset.
- vi. Effective knowledge management. 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. Appropriate records must be maintained throughout. In the UK, the SOF is the primary knowledge exchange forum.

2.1.2 Good Practices

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;

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, 31 headline recommendations to Store Operators are highlighted as good practices and assigned a specific label, GPn. The Good Practices are summarised in Section 7., and listed 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.

GP	Outline Description (subsection)	GP	Outline Description (subsection)
1	Stakeholder engagement (1.4.3; 1.4.4; 4.1.2; 5.3.3)	17	Store design – environmental controls (4.3.1, 4.4.2)
2	Technical terminology (2.1)	18	Store design – contaminants (4.3.1, 4.3.2, 4.4.1, 4.4.2)
3	Technical competence (2.1.3, 3.2.1, 5.3.3)	19	Operational limits and conditions (3.3., 3.3.1, 4.4.1)
4	Human factors (2.1.3)	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 (3.1)	24	Maintaining intervention plans (5.3.3, 5.4)
9	Package materials (3.1, 6.6)	25	Access to rework facilities (5.3.4)
10	Maintaining transportability (3.1.3, 5.1.4)	26	Extending store operational lives (5.5)
11	Package evolutionary processes (3.2.2)	27	Establishing system baselines (6.2)
12	Package care and management – controlled (3.4)	28	Recording system performance (6.3)
13	Package care and management - uncontrolled (3.4)	29	Monitoring and inspection rates (6.4)
14	Local planning constraints (4.1.2)	30	Maintaining an archive (6.5)
15	Store design - monitorability (4.1.3)	31	Deployment of dummy packages (6.6.1)
16	Store design - life-limiting components (4.2.2)		

2.1.3 Approaches

Throughout the Guidance, 28 specific approaches are described and assigned a label, An, with a further overarching approach, A0, being defined as the overall Integrated Approach (presented in Figure 7 and Section 2.2 below). The other 28 approaches are listed below, with colour-coding as noted above.

A	Outline Description (subsection)	A	Outline Description (subsection)
1	Package Performance (2.1.3 a, 3.2, 4.4.2, 5.3.2, 6.1, 6.4.1, 6.6.2)	15	Package Movements – Export (5.1.4)
2	Integrated Human Factors (2.1.3b)	16	Package Emplacement (5.2)
3	Modifications to Existing Stores (2.1.3c)	17	Maintaining Package Safety Functions (5.3)
4	Safe containerised storage pending future treatment (2.1.3d)	18	Maintaining Environmental Conditions (5.4)

A	Outline Description (subsection)	A	Outline Description (subsection)
5	Selecting Package Designs (3.1)	19	Maintaining Store Life-limiting Features (5.5)
6	Package Evolution and Assessment (3.3)	20	Extending Store Lifetimes (5.6)
7	Lifetime Package Care and Management (3.4)	21	Baselining (6.2)
8	Development of Outline Store Design (4.1)	22	Monitoring and Inspection Techniques (6.3)
9	Store Longevity (4.2)	23	Monitoring and Inspection Rates (6.4)
10	Environmental Controls (4.3, 4.4)	24	Archiving (6.5)
11	Environmental Operational Limits and Conditions (4.4)	25	Inactive Samples and Simulants (6.6)
12	Package Movements - Import (5.1.1)	26	Auditing (6.7)
13	Inactive Commissioning (5.1.2)	27	Knowledge Management (6.8)
14	Package Movements – Operations (5.1.3)	28	Human Resources (6.9)

While most of the Approaches are outlined within specific subsections of the Guidance, see subsection 2.2 and Figure 7, Approaches A1 to A4 are applied generically across the Guidance; these four generic Approaches are described in outline below, and expanded, as appropriate, in specific subsections. For example, Approach A1 is also discussed in detail in Section 3.2.

(a) Approach A1 - Package Performance

Approach A1 (Package Performance) is used widely within the Guidance. It describes package performance zones (see Figure 3 below) across the waste management lifecycle from packaging through to disposal. A1 [34] is integrated within many of the other approaches, e.g. see A15 (Package Movements – Export) on maintaining package safety functions.

The purpose of A1 is outlined below and shown figuratively in Figure 3; further details of its implementation are in subsection 3.2. A1 was established through workshops and engagement with the NWDRF. It can be utilised by Store Operators as an aid to:

- highlight package components which would benefit from being monitored and/or inspected;
- derive appropriate store WAC;
- 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.

Although the approach is focussed on the waste package, it may be adapted to include aspects of maintaining the storage environment and life-limiting components of the store

itself, see subsection 4.2. 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 also of store parameters if the performance zone approach of Figure 3 is extended to store life-limiting components (see A19 (Store Life-limiting Features) and A21 (Baselining)).

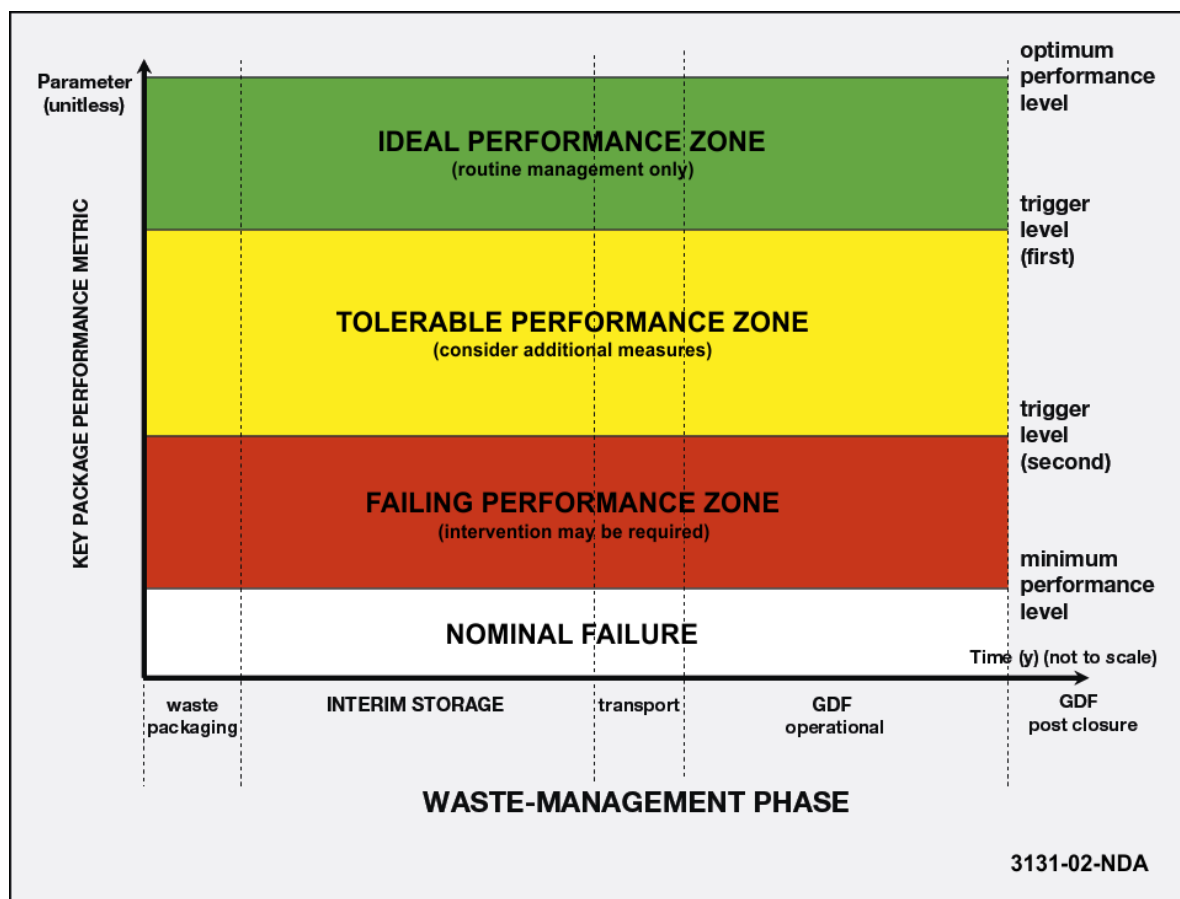


Figure 3 Basic Illustration of Approach A1 (Package Performance)

(b) Approach A2 - Integrated Human Factors

Approach A2 (Integrated Human Factors) is taken from Reference [35], 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 [36].

The HF Approach should be instigated as early as possible in the storage system's lifecycle. By following A2 (Integrated HF), and the identified toolkit – see HF2-HF15 in Reference [35]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.

(c) 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 should be addressed. Much of the Guidance is based on the operational experiences of existing storage systems in the UK. However, this collective operational experience was not available during the design and planning phases of these older stores. Indeed, many of the stores were designed before the current long-term management strategies of HAW were established – see Section 1. Additionally, new technologies continue to emerge with the potential to improve the operations of the storage system and ongoing R&D activities provide a firmer understanding of how the storage system may evolve in the longer term. However, the design of many older stores, especially those designed for non-contact handleable packages, may severely constrain any proposed improvements. While this might have implications for the lifetimes of these older stores, they do offer opportunities for learning that can feed into future store construction.

Briefly, A3 (Modifications to Existing Stores) - see Figure 4 - 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), best available technique (BAT) in England and Wales or best practicable means (BPM) in Scotland 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; and
- implementing and then periodically reviewing the decision.

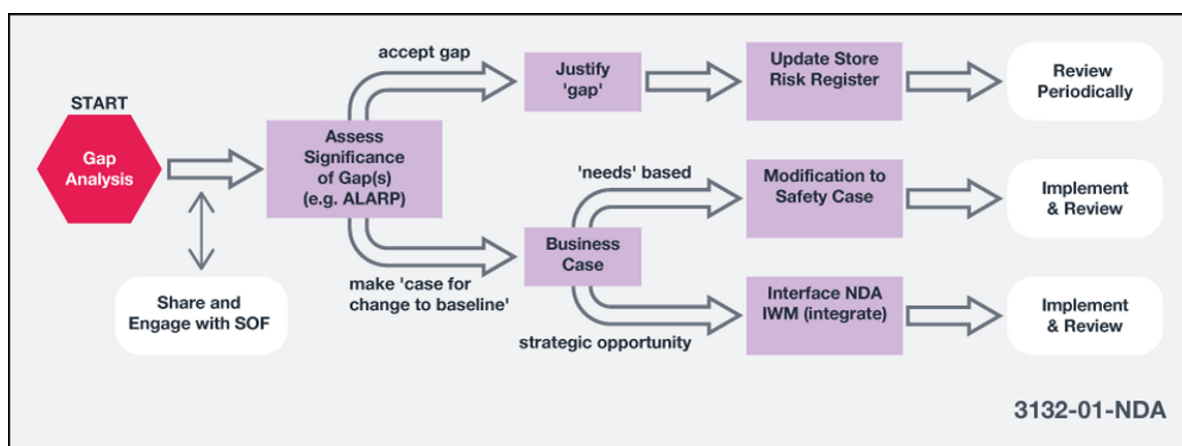


Figure 4 Simplified Flow-diagram of Approach A3 (Modifications to Existing Stores)

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.

(d) Approach A4 – Safe containerised storage pending future treatment

This describes an approach where a multistage packaging strategy is adopted as opposed to a single stage or immediate conditioning into a disposable waste product. Such strategies may be implemented to provide:

Decay storage

Decay storage is recognised in the NDA HAW strategy [11] to be suitable for wastes mainly 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 as LLW, VLLW or reuse). The benefits of such approaches could include:

- providing opportunities to develop new technologies and use simpler processing techniques;
- increasing the potentially available waste management routes (e.g., disposal as LLW or VLLW to the near-surface environment);
- increasing the range of applicable treatment options and management routes, perhaps using off-site facilities, thereby reducing project and programme cost and risk;
- providing operational benefits, such as reduction in worker radiological exposure (supporting demonstration that risks are ALARP), or enabling the reclassification of waste; and
- reducing the discounted cost of waste management, owing to deferring conditioning and treatment until the end of the storage period, noting that there is also a clear waste management benefit

In the considerations for decay 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 LLWR.

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

Interim storage in engineered stores

This is a waste package that, in its proposed state for storage, may not be directly disposable, but is expected or has the potential to form part of a future disposal solution.

Two generic types of interim product can be defined:

1. The waste is in a disposal container, but may require dewatering, encapsulation, void filling and/or some other form of processing prior to disposal; this implies that a finishing facility that includes a processing/encapsulation plant may be needed. There is a spectrum of potential requirements for finishing, from none (e.g. if the case is made that further processing is not required) to significant and intrusive processing.
2. 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, as above; this implies

that a waste packaging facility would be needed, potentially including a processing/encapsulation plant.

The benefits of the approach could include:

- reduction of radiological risk associated with the current control of the waste; allowing action before finishing solutions are selected, developed and/or implemented;
- affordability;
- enabling knowledge gaps relative to the development of a treatment process to be filled during the period of interim storage;
- resolving technical risks;
- 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);
- achieving specific benefits when considering the development of interim products as part of an integrated waste management strategy;
- not foreclosing other waste management options where there is no significant detriment to system performance and a clear optimisation argument can be made;
- providing an enabling step for broad front decommissioning; and,
- providing operational benefits, such as reduction in worker radiological exposure (supporting demonstration that risks are ALARP).

Adoption of these approaches will require justification with the UK regulators and clear demonstration of ALARP and BAT/BPM [101]. They may place additional requirements on stores operators for additional operational controls and planning practices. The principles, approaches, good practices and tool kits 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, of particular consideration should be the requirements established within sections on characterisation, condition monitoring and inspection, learning plans, knowledge management and selecting package designs.

2.1.4 Toolkits

A toolkit is a list of potential techniques or solutions derived from operational experience and R&D. Toolkits, which are assigned in the text with a superscripted 'TKn', are listed below:

TK	Outline Description (subsection)	TK	Outline Description (subsection)
1	Human factors (2.1.3b)	13	Non-physical package intervention (5.3.3)
2	Basic container designs (3.1)	14	Physical package intervention (5.3.3)
3	Container materials (3.1)	15	Environmental control changes (5.4)
4	Encapsulants (3.1)	16	Life-limiting component repairs (5.6)
5	Package evolution models (3.3.3)	17	Baselining (6.2)
6	Packaging innovations (3.5)	18	Sample types (6.3)
7	Outline store designs (4.1.1)	19	Package inspection and monitoring (6.3.1)
8	Store life-limiting features (4.2.2)	20	Environmental condition monitoring (6.3.2)
9	Temperature and relative humidity controls (4.3.3a)	21	Monitoring life-limiting components - unshielded stores (6.3.3)
10	Moisture controls (4.3.3b)	22	Monitoring life-limiting components - shielded stores (6.3.3)
11	Contaminant controls (4.3.3c)	23	Monitoring and Inspection rate models (6.4.1)
12	Microbial and animal controls (4.3.3d)		

2.2 Roadmap

When the sections are integrated and applied in an iterative manner, the Integrated Approach (A0) shown in Figure 8 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.

The Guidance may also be used as a reference, for example to identify potential solutions to specific issues that may arise. Additionally, through the accompanying database, the Guidance can be used to identify suitable contacts and underlying detailed work to support development of new tools and encourage dissemination of lessons learned.

For planned stores, key factors which may discriminate between storage system designs are shown in Figure 8. See also Section 3 and Section 4. However, as shown in Figure 9, the process is iterative with the store design and package design intimately linked. 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 9, 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 8 are taken from Reference [38]. 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 [29]. Some SLCs may use a different waste classification to the groups in Figure 9 but the key waste characteristics for storage will be the same.

The Joint Guidance [29] 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.

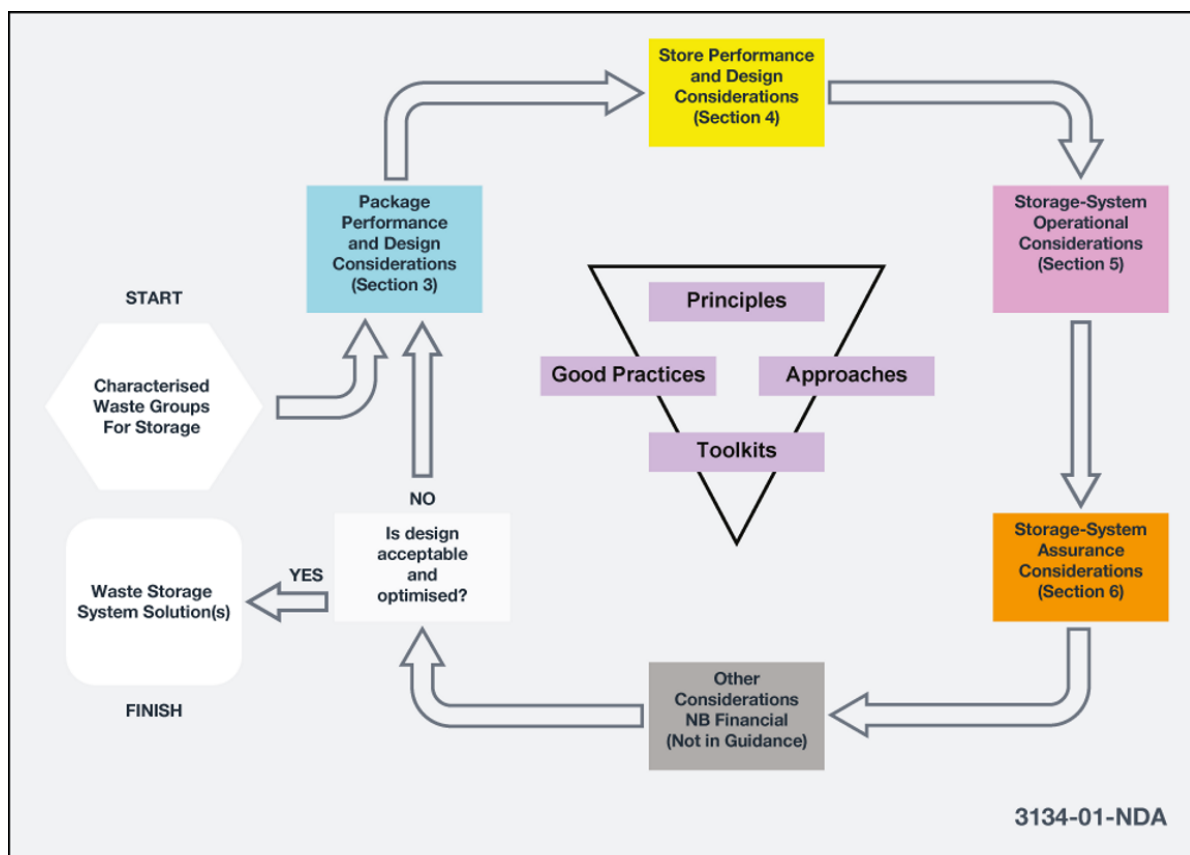


Figure 8 Schematic Representation of the Integrated Approach A0.

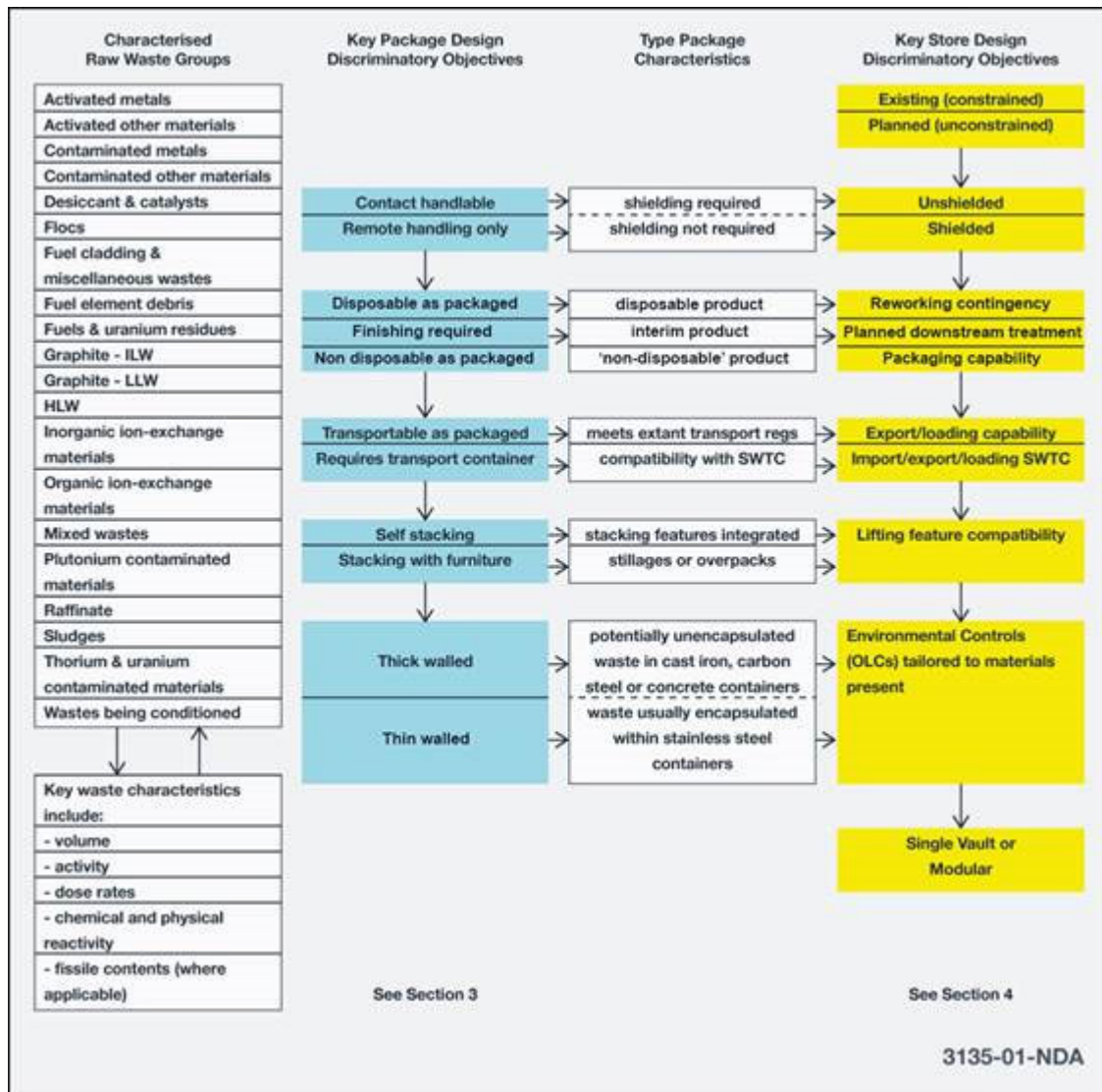


Figure 9 Key Storage System Design Discriminators and Characteristics

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. The Group is sponsored by the Strategy and Technology Team in NDA's Integrated Waste Management Directorate.

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 Change control process

The NDA Sponsor of the Guidance is the Head of Integrated Waste Management, with implementation through the Head of Programmes. 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.

3. Package Performance and Design

This section comprises of 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).

3.1 Approach A5 – Selecting Package Designs

Approach A5 (Selecting Package Designs), set out below, describes steps to establish a robust waste package design:

- Determining appropriate package design objectives - see also Figure 9. It should be noted, in Figure 10, the essential role of the waste package in providing two fundamental barriers of protection - i.e. the conditioned wasteform and container - which will need to be provided across the package lifecycle. There are several package design objectives to consider that will influence the design, including:
 - a) handleability - see subsection 3.1.1;
 - b) disposability, after finishing if required - see subsection 3.1.2;
 - c) transportability - see subsection 3.1.3;
 - d) stackability - see subsection 3.1.4; and
 - e) containment functionality - see subsection 3.1.5.
- Reviewing existing package designs for suitability. RWM has published specifications for several standard designs of waste containers; RWM Packaging Specifications and Guidance NotesTK2. Common variants of the standard container designs, based on licensee requirements, are also available, for example Reference [40]. 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).
- Establishing suitable materials to meet the design objectives. Various materials may be considered in the package design that will strongly influence, inter alia, the

nature of any environmental controls. Materials employed in the external features of container designs and will be directly affected by the storage environment, include:

- a) stainless steel grades, including austenitic such as 316L and duplex such as 2205;
 - b) carbon steels, including lower carbon grades such as mild steel;
 - c) ductile cast iron;
 - d) reinforced concrete, such as used in 6m³ concrete boxes; and
 - e) other materials, which remain under consideration in the UK for specific applications.
- In all cases, the materials chosen in the package design must be shown to be sufficiently robust for the intended lifecycle [29]. It is recommended that samples of materials are incorporated into a monitoring programme at an early stage of planned development, and consideration be made of accelerated ageing techniques, to establish a credible baseline. See GP9 (Package materials).
 - Ensuring the potential for adequate package performance - see subsection 3.2.
 - Considering emerging innovations which may enhance the packaging toolkit - see subsection 3.5;
 - Ensuring consistency with the store design and vice versa - see Section 4.

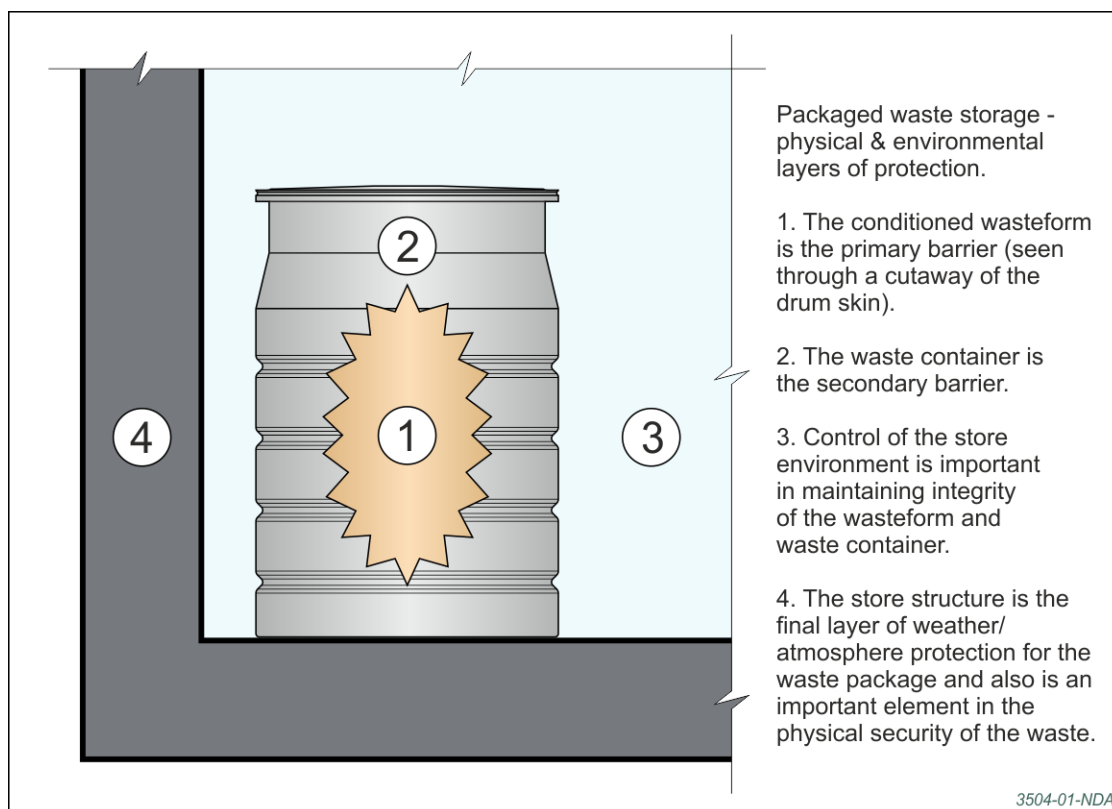


Figure 10 Representation of the Storage System

3.1.1 Handleability

- a. Contact handleable packages. The direct radiation arising from such packages, by virtue of the wastefrom properties and/or those of the container and any deployment of internal 'shielding material', is sufficiently small to permit direct contact handling of the package under normal operating conditions. These limits may vary depending on whether the packages are moved on-site or in the public domain, and on the likely human interaction requirements. Examples include: 2m, 4m and 6 m³ boxes, and Ductile Cast Iron Containers (DCICs), which are usually considered exclusively in this context.
- b. Remote (non-contact) handleable packages. The direct radiation arising from such packages requires remote operations to manage and move them under normal operating conditions and use of transport containers, which are shielded overpacks, to transport them. The 500 litre drum and 3 m³ box are the typical basic designs, although these may also be suitable for some contact handleable waste streams.

3.1.2 Disposability

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:

- a. the required use of a transport container at export to meet transport regulations;
- b. 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. For example, container designs with a double skin with the option to encapsulate between skins later if necessary; and
- c. 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 Section 3.1.3). See Disposability Assessment Principle 8 in RWM guidance on disposability assessment of packaging proposals [33].

- b) In the case of HAW to be stored under a safe containerised storage pending future treatment approach (A4), it may be appropriate to choose a type of packaging that would facilitate subsequent management and disposal of the waste as LLW.

3.1.3 Transportability

Although the nature and composition of the inventory is restricted, many containers for contact-handleable packages are also designed to meet the requirements for an Industrial Package as specified by IAEA Transport Regulations [17]. The need to maintain the transport licence, during storage, should be carefully planned and managed and the appropriate Design Authority engaged. For such packages a clear linkage between the transport safety case and the storage safety case should be maintained and documented. Transport packages must be shown to be robust to certain prescribed threats. New and existing designs may be required to meet future regulatory requirements, e.g. in response to future security needs. See GP10 (Maintaining transportability).

Remote handleable packages will generally require the use of a transport container, for example the Standard Waste Transport Container (SWTC), as specified by IAEA Transport Regulations [17] for transport as a Type B transport package. However, given the timescale of interim storage, it may be that some packages will have had sufficient radioactive decay to permit less onerous transport requirements when exported from the storage facility.

Codes of practice on radioactive materials transport are maintained and developed by the UK nuclear industry's Transport Container Standardisation Committee (TCSC). Further guidance can also be found on the ONR web page for Transporting Radioactive Material.

3.1.4 Stackability

There are many advantages from package designs which permit direct stacking. However, for greater flexibility, stillages are commonly used to support stacking arrangements of 500 litre drums and similar packages. Other approaches include use of concrete overpacks for 3m³ boxes and drums. Use of such furniture is discussed in Section 4, and hence there is no further consideration given under the package design approach.

3.1.5 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 [41] afforded from the waste package as shown in Figure 11. Where thick-walled containers are selected, i.e. with a wall thickness typically $> \sim 10$ mm, and generally much more, the containment is usually provided to a significant extent by the container walls with limited contribution from or need for an encapsulant. Depending on the waste characteristics, thin-walled containers typically place greater reliance on the encapsulated wasteform for passivity, physical strength and containment.

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). Other materials, such as thermoset polymers, are also used, particularly where it is desirable to keep waste components dry to minimise gas generation.

Two advantages of using OPC-based cementitious encapsulants during interim storage are their high pH, which promotes low rates of internal steel corrosion, and their capacity to neutralise any acidic by-products, which may arise as some waste groups evolve, e.g. organics. However, the long-term supply of appropriately specified cementitious materials is under threat [42]. Until packaging is completed, alternative encapsulant materials, and suppliers, should be kept under regular review supported by proportionate research as necessary to maintain credible alternatives. 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.

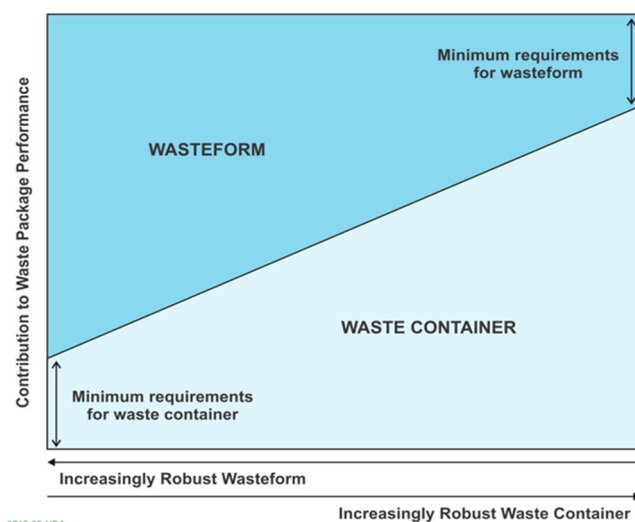


Figure 11 Illustration of Wasteform Versus Container Contribution to Performance

3.2 Approach A1 - Package Performance

3.2.1 Overview

A1 (Package Performance) [34], see subsection 2.1.3a, consists of the following steps:

- defining the stages of the relevant lifecycle, e.g., see x-axis in Figure 3;
- identifying waste package 'groups' likely to evolve in similar ways within the store - see Figure 9;
- identifying the package safety functions over the lifecycle for each identified waste package group - see subsection 3.2.2;
- identifying evolutionary processes that may affect the performance of the safety functions and measurable indicators of these processes - see subsection 3.2.3; 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 3.2.4.

A1 (Package Performance) should be applied proportionately according to the categorisation of the waste package(s) - see Appendix 1 of Reference [29] - 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 [43].

3.2.2 Storage safety functions

The following primary safety functions, see Table 1, have been defined for waste packages during interim storage - see also References [32,34]:

- 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 [44].
- 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.
- 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. 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 [34]. See GP11 (Package evolutionary processes).

Table 1 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
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 /	(i) internal properties

Storage safety function (main component delivering function)	Example evolutionary processes	Potential indicators
	distribution of fissile material	

3.2.3 Evolutionary processes and indicators

Effective application of A1 (Package Performance) requires suitable understanding of how the waste package may evolve under the conditions provided by the storage system. While there has been considerable R&D since the 1980s, for example the Product Evaluation Task Force (PETF), the potential for longer storage durations and new waste packaging techniques, has meant that research has continued to be commissioned by RWM, SLCs, and universities to understand the longer-term performance of waste packages.

Waste packages, and hence their properties and performance, will inevitably evolve during interim storage at variable rates. It is reasonable to expect CM&I in the case of containerised storage pending future treatment to focus on ensuring that containerised unconditioned or partly conditioned wastes are evolving as expected. This evolution is likely to be of greater significance and different in nature to that associated with a fully conditioned passive waste form. However, safety function performance 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.

The evolutionary processes, which may affect the safety functions, should be identified and documented by the Store Operators, backed up, as necessary, by on-site expertise, contractors or engagement with RWM through the disposability assessment process. The measurable indicators of these evolutionary processes, which can be related to the safety function performance, should then be identified. This should also form part of an effective monitoring and inspection approach (see subsection 6.3), i.e. an approach focused on the measurable properties that have the most significance.

Table 1 outlines example evolutionary processes which could affect the package safety functions and suggests indicators of the degradation processes which could, in principle, be measured. It is important to note that ‘indicators’ is used to identify both direct evidence or measurements of processes, such as the extent of corrosion, as well as factors that are known to cause or increase the risk of degradation such as salt contamination. An overview of evolutionary processes is provided in subsection 3.3 and Reference [41].

3.2.4 Performance zones

For each safety function, see also Reference [32], the performance defined by relevant measurable indicators should be assigned to one of three performance zones, as illustrated in Figure 3:

- 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. Many indicators provide performance information for several safety functions, as shown Table 1.

The performance zones in the Guidance are represented as being constant throughout and between phases. This is a simplification. For example, during transport, IAEA prescribed requirements [17] may be provided to a significant extent by a transport container such as the 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;
- 1st 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;
- 2nd 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.

3.3 Approach A6 - Package Evolution and Assessment

Approach A6 (Package Evolution and Assessment) consists of the following steps, many of which may be iterative steps when the applied to storage systems being planned:

- characterising the waste, especially with respect to chemical and physical reactivity after packaging;
- defining container -, shielding materials and, even when encapsulation may be planned after storage (i.e. interim products), encapsulants as appropriate;
- identifying the environmental conditions to be provided by the storage system;
- identifying the wastefrom-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 Operational Limits and Conditions (OLCs) (Approach A11) and the development of an Environmental Control Approach (Approach A10);
 - wastefrom evolution processes, see subsection 3.3.2; and
 - long–term package evolution, see subsection 3.3.3.
- assessing the implications from evolution, see Figure 3;
- 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 [41].

3.3.1 Container corrosion

The main factors affecting the external and internal corrosion of the waste container, see Reference [41], during interim storage, include the:

- 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 cement surrounding them;
- presence of liquid water in contact with the surface, notably in crevices;
- temperature of the surface;
- presence of ionic species in solution and in contact with the surface;
- presence of nutrients able to sustain microbial growth;

- radiation dose rates.

The forms of corrosion [41,45,46,47,48,49], most relevant to interim storage are:

- a. 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 [45]. Duplex grades [46] are expected to be at least as corrosion resistant. Unprotected carbon steel and cast iron surfaces are more susceptible [47]. For concrete containers, general corrosion of the rebars upon carbonation and exposure to chloride is expected to be a relevant degradation mechanism.
- b. 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) [45]. Stainless steel, under normal operating conditions, especially at coastal sites, may be expected to require active controls to prevent the initiation and propagation of localised corrosion and SCC. However, duplex grades are typically more resistant to SCC [46]. Localised corrosion can also occur in concrete containers in the presence of high chloride concentrations.
- c. 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 [41].

There has been extensive testing since the 1990s on predominately stainless samples under laboratory conditions to investigate localised corrosion and SCC mechanisms and establish operational 'limits' [50]. Work also evaluated the effects from MIC [50,51]. However, evidence to date from UK stores and other monitoring programmes, see for example [52,53], suggests that the experimental studies are overly cautious in determining performance needs during interim storage as described in subsection 4.4.2. Much work has been carried out through the RWM research programme to define operational limits under realistic storage conditions [48, 49]. This is discussed further in subsection 4.4 Approach A11 - 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 over interim storage timescales. The following processes are considered notable, see also Reference [54], 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:

- a. 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, reduced temperatures are beneficial to control these effects. Experimental work which has demonstrated that mechanical 'shocks' to packages [55] may disturb protective corrosion products leading to short-term enhanced corrosion rates until the corrosion layer reforms.
- b. Internal cementitious reactions, where these may lead to gross dimensional change (swelling or shrinkage) of the wasteform. Good encapsulant formulation, and long-term inactive development trials, should reduce the risk.
- c. Radiolysis of sensitive organic materials, which may break down into reactive species. Segregating sensitive packages in areas of lower dose is a potential method to mitigate the effect.
- d. Carbonation of cementitious encapsulants and concrete containers [41], which will change the wasteform properties, such as gas permeability and pH buffering capacity, over time. The implications from carbonation, if any, are context-specific.
- e. 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.

The failure mechanism for dried or polymer-encapsulated wasteforms may differ from that of cement-encapsulated waste forms. For example, radiolysis of polymers may lead to mechanical failure of polymer wasteforms.

3.3.3 Evaluation of package evolution toolkit

The following comprises a toolkitTK5 of models which may establish package evolution:

(a) Gas generation

It is recommended that Store Operators 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, MAGGAS [56], 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 [57]. 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.

(b) Wasteform expansion

RWM has developed specific modelling calculations [58] 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.

(c) Corrosion

RWM 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 [59]. 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 A7 - Lifetime Package Care and Management

A good package care approach is outlined in a report [60] and provides a framework for Approach A7 (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, A7 is applicable more widely. Key stages considered, across the lifecycle up to import into a store, include:

- manufacture of container;
- storage of container at manufacturer's site;
- transport to site;
- receipt of containers at site;
- storage and inspection prior to use;
- repair of damaged containers;
- handling, filling and immobilisation as appropriate; and
- cross-site transfer of package to the store.

The following practices are highlighted:

- a. 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.
- b. 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.
- c. 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.
- d. For carbon steel and cast iron containers lifting and handling procedures should minimise the potential for scratches and damage of any corrosion protection system which may be applied.
- e. 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.

- f. During transport and on-site transfers precautions should be taken to protect the packages from physical damage and exposure to de-icing salt as these typically contain high amounts of chloride. Ideally, the choice of de-icing salt on a site should exclude the use of specific salts such as sodium chloride and magnesium chloride, where import of these salts may have an impact on the store environmental control. Typically, this might be most relevant for the import of shielded containers over salted roads, or use of transportable equipment used to access (unshielded) stores.

3.5 Innovations toolkit

The following waste-package initiatives TK6 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

- direct disposal of waste packages, 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;
- improved implementation of the waste hierarchy principle, with segregation of components for reuse, recycle and prompt disposal as Lower Activity Waste (LAW); and
- decay storage management opportunities are captured within A4.
- 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

- 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

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

- use of additives such as superplasticisers to improve the workability of encapsulants.

(d) Containers

- use of steels with enhanced localised corrosion and SCC resistance, such as duplex grades;
- use of concrete containers, such as 6m³ concrete boxes, and other types of robust shielded container; and
- use of alternative container designs, which minimise the need for size reduction of raw waste components but may require more flexible store lifting capability.

4. Store Performance and Design

The primary function of a waste package store is to store waste packages in a manner that protects workers, the public and the environment from hazards associated with the interim storage of waste packages until they are exported. This function may be conveniently divided into two components:

- (a) Maintain the waste packages through:
 - provision of safe, secure, reliable and monitorable storage space for packages;
 - preserving the package safety functions;
 - ensuring the continued operation of handling, monitoring and other equipment;
 - ensuring the integrity of key components of the storage system;
 - retaining knowledge and records of the wastes, equipment and infrastructure;
 - and
 - retaining the ability to promptly retrieve packages for export to other processing/storage plant or GDF.
- (b) Protect workers, the public and the environment through:
 - containment of radioactive material;
 - protection against ionising radiation to ensure doses are ALARP; and
 - protection against criticality, where appropriate.

4.1 Approach A8 – Development of Outline Store Design

Approach A8 (Development of Outline Store Design) provides key factors to identify a suitable outline store design, see also Figure 9, including:

- a. waste package derived requirements; see Section 3. The design must cater for the number of packages expected and manage the associated hazards such as shielding requirements. Where there is uncertainty in the capacity required then 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;
- b. existing basic designs to act as a template for the design; see subsection 4.1.1;
- c. fundamental store design requirements; see subsection 4.1.2;

d. system components requiring up-front consideration; see subsection 4.1.3.

4.1.1 Current designs

There are several basic HAW stores designs^{TK7} used in the UK and overseas [61]. 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 9. The basic designs of stores are identified as:

(a) Stores for Contact Handleable Packages:

- Vault designs, with no additional shielding necessary from the store structure compared with the examples below; and
- 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:

- Vault designs, with packages stored in flexible bay areas and shielding an integral part of the store design;
- Charge plug, with packages stored in fixed vertical arrays and shielding an integral part of the store design; and
- 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 may be used to stack packages efficiently. These are used widely in the UK. Their potential deployment should be a design consideration and treated as a component of the store's infrastructure and a potential life-limiting feature - 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) 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 rates. See subsection 4.2.2.
- b) Hazards. The design must take due account of all foreseeable hazards relevant to the site [62,63]. Notably, these include climate change effects such as sea level rise, see Reference [61], and tsunamis. The design of the facility should prevent in-leakage of water. See subsection 4.2.2.
- c) Regulatory and legal requirements, including:
 - I. Health and safety, including nuclear safety. For example, the Construction (Design and Management) Regulations 2015 (CDM) [64], 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 store and associated equipment can be safely maintained. 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, waste hierarchy, avoiding secondary wastes, authorised discharges and preventing animal ingress. Consideration should be made of the eventual need to decommission the facility [65] and minimising its impact [29];
 - III. Security. The outcomes articulated in the ONR's Security Assessment Principles [28] 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 are 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-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 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.
- d) 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 and package designs 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 government policy, regulatory requirements, and shown to be cost effective.

4.1.3 Significant system components

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

- a) Ventilation. Whether or not a forced ventilation system is needed should be assessed based on significance or risk. Comprehensive Guidance 'An Aid to the Design of Ventilation of Radioactive Areas' is available [66]. See also subsection 4.3.3e.
- b) Environmental monitoring systems. 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 6.3.2.
- c) 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.

- d) **Emplacement approach.** 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.
- e) **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 and other life-limiting components as appropriate. See GP15 (Store design – monitorability) and subsections 5.3.4 and 6.3.

4.2 Approach A9 - Store Longevity

Approach A9 (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;
- establishing appropriate quality controls - see subsection 4.2.3;
- considering the need for refurbishment and replacement - see subsection 4.2.4.

Approach A9 therefore comprises several activities associated with Asset Management. Asset Management is an internationally recognised approach to ensure that an asset, in this case a HAW store (supporting the HAW package and the facility itself), is managed to ensure its satisfactory operation through to final disposal (HAW package) or decommissioning (facility). Application of Asset Management principles is discussed further in Section 5.5.

Asset Management requires understanding and control of the lives of the systems and components within the HAW 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 that 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 and 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

In order 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 [61]. Once these are identified this can be used to inform the maintenance and refurbishment schedules. See GP16 (Store design – life-limiting components).

Generic life-limiting features and components TK8 can be separated into those related to the design, management and continuing operation of the store and equipment.

- a) Life-limiting features relating to the design of the store and its equipment include:
 - 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;
 - Siting requirements, in so far as they affect the external factors listed above; and:
 - storage capacity
 - local demographics
 - hydrogeological properties.
 - Regulatory and stakeholder views, including:
 - planning and permitting issues
 - stakeholders' perceived environmental and safety considerations
 - socio-economic factors and cost issues
 - changes in regulatory requirements.
- b) Life-limiting components relating to the continued operation of the store and its equipment include:
 - 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,
 - elements to exclude water and control inadvertent surface water deposited on the floor
 - integrity of external cladding.
 - Operation of plant and equipment, including:

- general obsolescence of components and replacement parts
 - 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.
- c) Life-limiting features relating to the management of the store and its equipment include:
- Knowledge management issues, see A27 (Knowledge Management), including:
 - availability of staff with appropriate skills, knowledge and experience
 - organisational learning and knowledge capture
 - records management for waste packages, environment, store equipment and store maintenance.
 - Security.

4.2.3 Establishing Quality Standards and Controls

All life limiting features should be subject to appropriate quality standards and control. In particular, the use of appropriate concrete grades and of 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; provision of additional safety margins; and the use of stainless steel reinforcement.

4.2.4 Refurbishment and Replacement

Not every component in a store need 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, control systems, software and major reinforced concrete or structural steelwork building structures. Figure 12 taken from Reference [61], 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].

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.

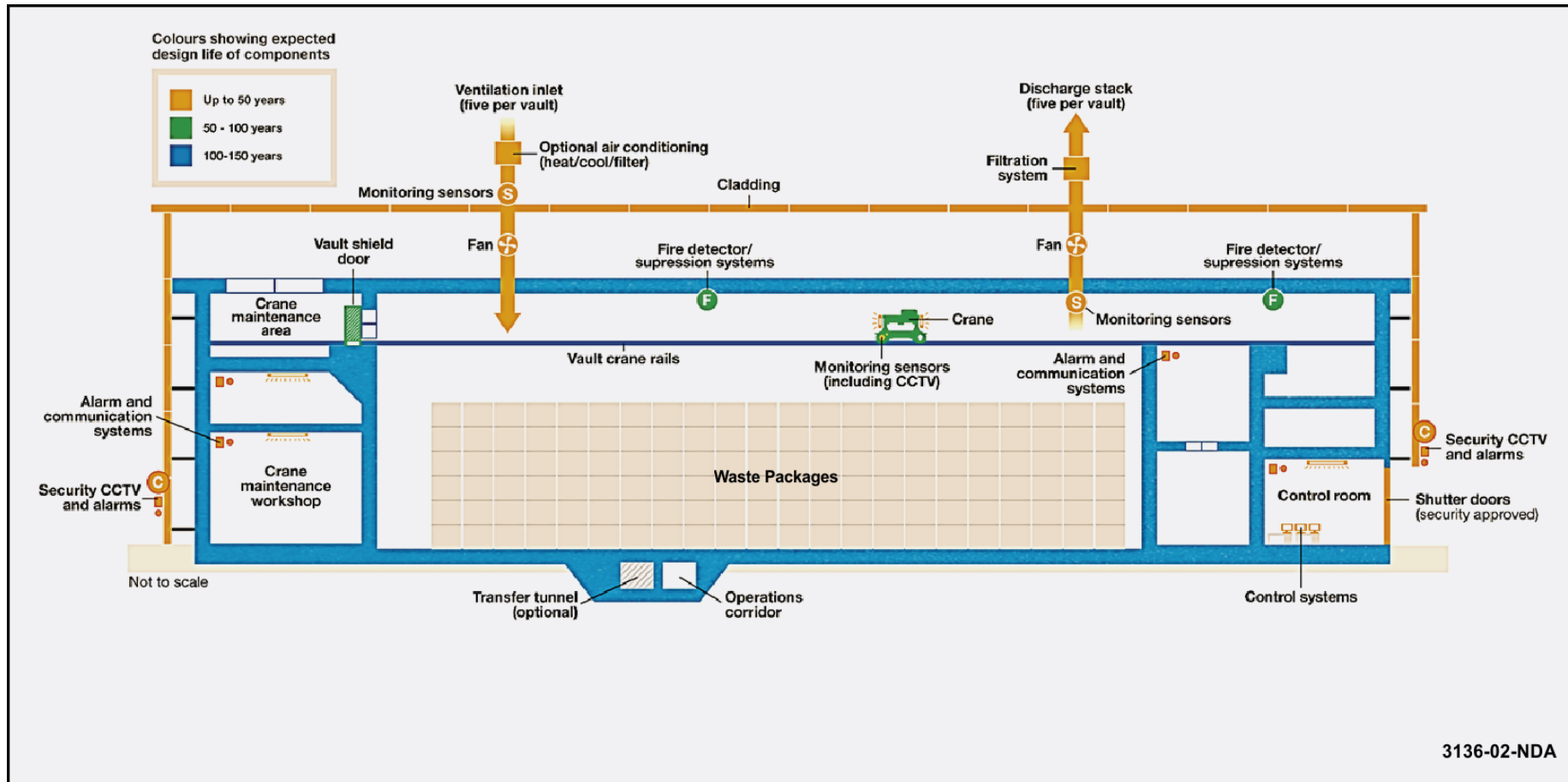


Figure 12 Representation of a Shielded Vault Store with Component Lifetimes

4.3 Approach A10 - Environmental Controls

Approach A10 (Environmental Controls) should be considered for both planned and existing stores, given the fundamental importance of the store environment - see Figure 4.

A10 comprises the following steps:

- a) setting control objectives, see subsection 4.3.1;
- b) identifying constraints, see subsection 4.3.2;
- c) 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. Where control of contaminants cannot be assured, it is also important that the RH is maintained below or sufficiently above the deliquescence point of any contaminant salts on sensitive materials. 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 of 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;
- providing homogeneous environmental conditions spatially through the store; 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

- a) 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 environment controls should take this into consideration.
- b) 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 [29] 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.
- c) maintaining disposability, should consider guidance available from RWM [67], and any other future finishing, storage or disposal requirements. Any caveats noted in relevant LoCs, concerning the environmental controls, should be observed. Maintaining the environmental conditions of transportable packages, where prescribed, should also be observed.
- d) location, including:
 - whether the site is inland, or coastal and specifically the composition of salt deposition in the locality of the proposed store - see GP18 (Store design – contaminants);
 - the long-term trends for local temperature and relative humidity. It is also necessary to take account of potential extreme weather events, and likely future climate changes over the next 100+ years; and
 - 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.

- e) availability of existing site infrastructure such as ventilation systems 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; and
 - the target RH of the environment should be tailored around the nature of the contaminants potentially deposited on store life-limiting features and waste packages.

Controls (Temperature and relative humidity controlsTK9) include:

- passive controls reliant on the store design features;
- actively managed Heating, Ventilating, and Air Conditioning (HVAC); and
- a contingency plan should be established if the primary method fails to deliver the required performance or breaks down during operation [66].

In all cases, the performance of the temperature and relative humidity 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:

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; and
- 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

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.

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.

Controls (Moisture controlsTK10) 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, e.g. roofs and gutters;
- 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; and
- internal or external tanking, cladding or roof decking to raft, walls and roof respectively
- 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.

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.

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. Presence of iron, such as carbon steel, has been observed by RWM [53] to form superficial rusted spots on stainless steel containers.

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 [68] and (d).

Controls (Contaminant controlsTK11) 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; and
 - covering or moving seasonally any transportable packages to avoid contamination by road de-icing salts.
- 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.

Potential controls (Microbial and animal controlsTK12) 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 [51];
- maintaining a low RH, 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; and

- prompt removal of any animal ingress while observing relevant legislation for protected species
 - 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, 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 ‘fresh air’. This could reduce operating costs, and would ensure lower intake of contaminant aerosols and provide more stable temperature and relative humidity but may raise issues in terms of accumulation of hazardous gases;
 - ducted mechanical air systems may lead to negative pressures and may promote infiltration of external (unfiltered) air. Poor store maintenance could also result in uncontrolled pathways forming; and
 - 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;
 - forced ventilation may be advantageous in cases in which waste is left to dry naturally.

4.4 Approach A11 - Environmental Operational Limits and Conditions

Approach A11 (Environmental OLCs), set out in this subsection, describes steps to establish a robust set of environmental OLCs with which to maintain the storage system in a safe state. A11, which should be applied in parallel with A10 (Environmental Controls), comprises:

- a) establishing which OLCs parameters to prescribe - see subsection 4.4.1;
- b) establishing robust limits - see subsection 4.4.2;
- c) 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: relative humidity (RH), temperature (T) and the surface concentration of potentially corrosive contaminants such as chlorides (Cl-) - 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 significant to waste package performance and life-limiting features.

For operational purposes, the 'dew point' may also be used as an OLC. Dew point is defined as the temperature at which the relative humidity of a given volume of air with a fixed water content would be 100%, resulting in surface condensation, with all other factors being equal [68]. Hence, the more the actual temperature is above the dew point, the better. However, this principle should be treated cautiously because salt contamination on surfaces can lead to deliquescence in conditions where the RH less than 100%. The dominant ionic species generally controls deliquescence conditions (e.g., NaCl for marine aerosols) but deliquescence of some species is temperature sensitive.

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. However, in practice (and where practicable) all three parameters should be managed in concert to provide defence in depth.

Additionally, the Joint Guidance [29] 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 OLCs

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-minimus level of risk such that observance of the 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 the 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. For example, stainless steel, mild steel, ductile cast iron or reinforced concrete boxes may all be expected to have different susceptibilities to corrosion and degradation.

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 keep temperature steady so as to 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 relative humidity – transient conditions increase the risk of condensation/deliquescence and may increase the risk of corrosion mechanisms occurring in specific RH ranges (e.g. SCC); and
- and, prevent ingress of corrosive contaminants into the store, including salt particles and aerosols from external sources , 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 6 m³ boxes and DCICs, will typically be stored in unshielded stores lacking forced ventilation. On the other hand, stainless steel waste packages such as 3m³ 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.

It may be challenging to control OLCs for packaged wastes in unshielded stores lacking environmental controls. For example, in such stores the doors may sometimes be open to the outside environment for forklift trucks to enter and exit. On the other hand, packages in such stores are easier to inspect, so it should be possible to carry out regular checks to detect signs of condensation, salt deposition or incipient corrosion.

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 relative humidity

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 temperatures low 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 particular concerns for some interim products.

Significant deposition of hygroscopic salt from the atmosphere (deposition density > 10-100 $\mu\text{g cm}^{-2}$) may occur over long storage periods, in all store types and on all packages, unless prevented by air inlet filtration [69]. Therefore, 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 this reason, especially over longer storage periods or in the presence of substantial initial salt deposition, stringent measures will be required to maintain waste packages and the store life-limiting features in good condition, especially for stainless steel. 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 this type of packages [47].

It may be difficult to demonstrate that all parts of a store, especially a vault store packed with closely spaced packages, is maintained at appropriate OLCs - such as temperature and humidity. 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.

The following sections describe the example 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 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.

a) 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 [68]. 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 2, see RWM's Waste Package Evolution Status Report [41]. 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 [48, 49].

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 $\sim 20^\circ\text{C}$ in NaCl), and that SCC is only observed at RH values 'close' to the deliquescence point of divalent chloride salts [71,72], above a minimum surface deposition density. An important observation is that divalent chlorides (CaCl_2 and MgCl_2) are much more corrosive than NaCl [48], but also much less abundant [73]. 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 2 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 [46].

Table 2: Representative risk based OLCs for storage system with 316L based packages, based on RWM’s Package Evolution Status Report [41].

		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]
	40 to 60(d)	<[100]	<[10]	<[10]	<[1]
		>[100]	[10-100]	[10-25]	[1-10]
	60 to 90(d)	<[100]	<[10]	<[10]	<[1]
		>[100]	[10-100]	[10-25]	[1-10]
	>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, CaCl₂ and MgCl₂.

(b) At temperatures below 10 °C (the 'CPT' for 316L in FeCl₃), corrosion is severely inhibited.

(c) Limited data above 50 °C, 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 MgCl₂ and CaCl₂. 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.

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b) 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 relative humidity. 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), 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 [47]. 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 [47]. 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 Ductile Cast Iron Containers (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 3. 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 3: 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
Relative Humidity [RH/ %]		Total deposition density [Σx / $\mu\text{g cm}^{-2}$] (b)			
		< 50(d)	<[100]	<[100]	>[10]
>[100]	>[100]		>[10]	>[10]	
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

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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 $10 \mu\text{g cm}^{-2}$).
- 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.

c) Concrete containers and infrastructure

Degradation of concrete waste packages, such as the 6 m³ concrete box, including cementitious and steel reinforcement materials and external metallic features, is 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 CO₂ [74]. A relatively low store temperature below 20°C combined with a low relative humidity (<50%) will reduce the risk of carbonation, and help to prevent initiation of reinforcing bar corrosion [74]. 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 [75]. Sulphate deposition may also lead to degradation reactions with the concrete and should be minimised [76].

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 4. It should be noted that a chloride surface concentration is not specified in Table 4. 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 relative humidity.

The rate of concrete carbonation increases with temperature and peaks at relative humidity 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 4 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 and manufactured concrete will be resistant to carbonation at relative humidity levels in excess of this value.

Table 4: 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)

(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

Ideal conditions to avoid / minimise degradation of container

Elevated degradation rate of container

Significantly elevated degradation rate of container

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It should also be recognised in specifying interim storage conditions that concrete packages, such as the 6m³ 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 Section 4.4.2.

4.4.3 Maintaining OLCs

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 A18 - Maintaining Environmental Conditions), is described in subsection 5.4.

5. Storage System Operations

This section comprises of 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 A12 – Package Import

Approach A12 (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 [17];
- complying with local on-site transfer requirements;
- making despatch and receipt checks against store WAC, 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 6.2, 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; 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.

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 as appropriate. Legal and facility requirements, for transport, storage or disposal, may also change over time potentially requiring package rework to assure compliance.

5.1.2 Approach A13 - Inactive Commissioning

Approach A13 (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. A13 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 13 provides a framework of issues to consider in support of the development of the Cold-Handling schedule for stores.

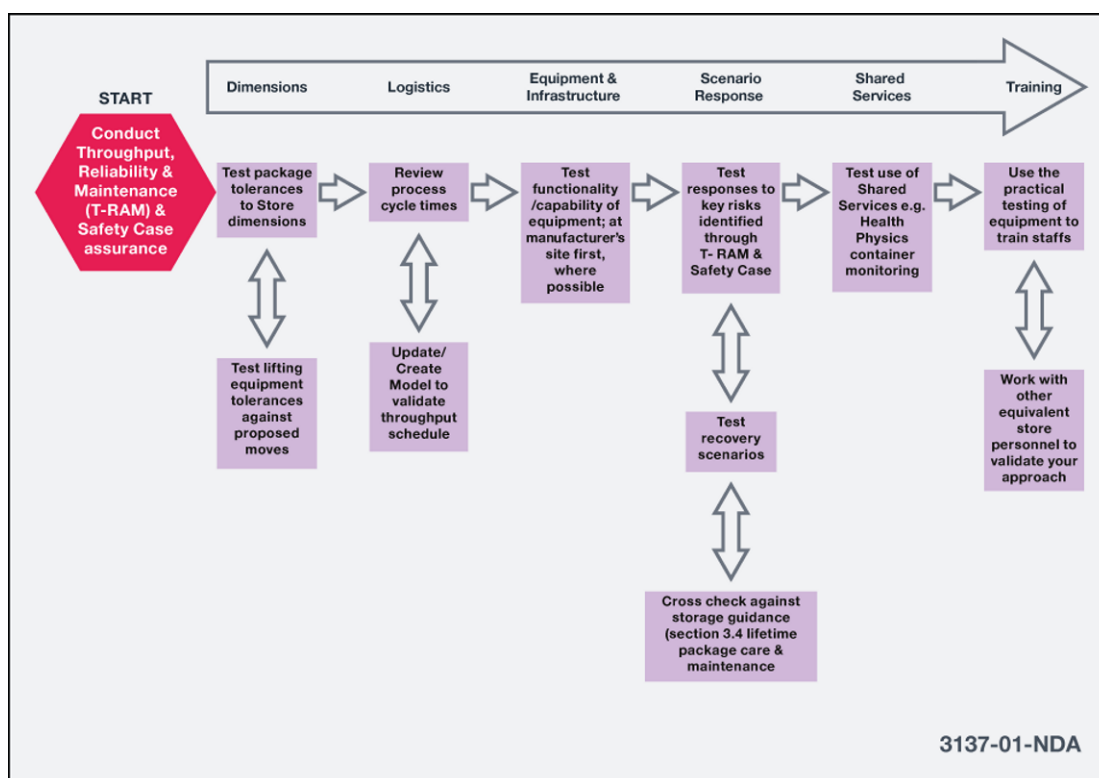


Figure 13: Indicative Inactive Commissioning Flow Diagram

As well as using A13 for inactive commissioning of a new store, a similar process may be needed if significant modifications are made to a previously operating store.

5.1.3 Approach A14 – Package Movements - Operations

Approach A14 (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 6.3.1;
- 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;

- regulatory requirements;
- waste receiver audits; and
- export.

5.1.4 Approach A15 – Package Export

Approach A15 (Package Export) outlines steps necessary to export packages to another off-site finishing plant, store or to the GDF. 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:
 - 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;
 - 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);
 - ensuring approved security measures are in place, including the Transport Security Plan;
 - additional substantiation or rework be carried out if the above cannot be assured;
 - confirm export throughput, status of lifting equipment, and access potential for interference such as possible maintenance outages; and
 - develop and implement a communication plan with key stakeholders and Regulators, e.g. with respect to route -planning, transport and security.
- b) Implementation, including:
 - checks of the SWTC, or equivalent, on receipt, including identification, confirm empty and not contaminated;
 - provide suitable control of transient conditions such as temperature, and contaminants;
 - 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
 - completion of package records for the store and receiving site.

5.2 Approach A16 - Package Emplacement

Approach A16 (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. 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 [77].

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:

- enhance shielding and security objectives;
- improve access for monitoring and inspection of targeted packages;
- reduce the overall life-time package movements, e.g. through specific layouts of aisles and package configurations;
- 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;
- where relevant, mitigate the risk of cross-contamination between conditioned waste packages and any containerised waste pending conditioning; and
- 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:

- 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;
- enhance the effectiveness of environmental controls - see subsection 5.4;
- facilitate exporting, e.g. packages planned for early export, where known, are re-assigned to convenient locations; and
- improve access to store infrastructure, including ensuring acceptable space for operators to gain access, to allow for maintenance, refurbishment or repair.

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 A17 - Maintaining Package Safety Functions

Approach A17 (Maintaining Package Safety 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 14.

Rework, to restore one or more package safety function, is defined [78] 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.

A17 comprises the following steps:

- a) avoiding the need for intervention - see subsection 5.3.1;
- b) assessing package evolution - see subsection 5.3.2;
- c) identifying intervention tools - see subsection 5.3.3; and
- d) considering the location to rework packages as necessary - see subsection 5.3.4.

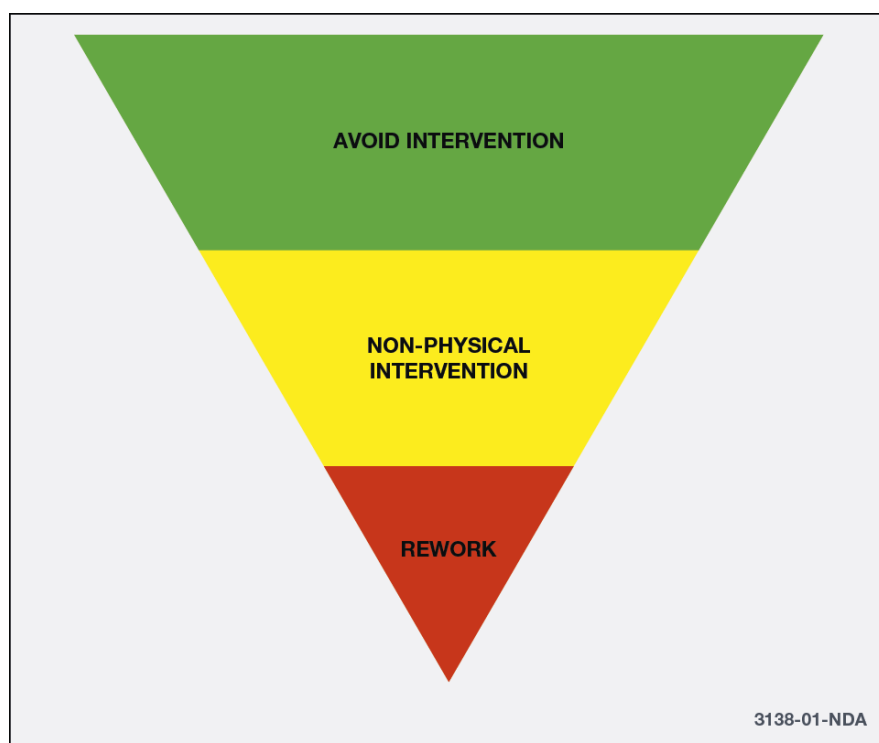


Figure 14 Package Maintenance Hierarchy

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 safety functions is consistent with a risk-based Asset Management approach, 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 requirements of 150 years (regulatory requirement) and 500 years (target requirement for 'finished' product) following the manufacture of the waste package; and Store Operational Life (100 years England and Wales, 300 years Scotland).

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 Section 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 as set out in the store's safety case 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, the expectation is that any intervention or reworking would be better carried out before import into the store - see subsection 5.1.1. Guidance is provided by RWM on the sentencing of such packages [79]; this also outlines the constitution of a 'sentencing body'. RWM notes the possibility [79] that as the GWPS 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, it is likely that a higher level of monitoring and inspection of waste and package evolution will be required.

It is assumed that packages are subject to a monitoring and inspection regime focussed on the appropriate indicators - see subsection 6.3. However, A1 should additionally be applied across groupings of packages, to identify four different patterns of potentially unexpected behaviour:

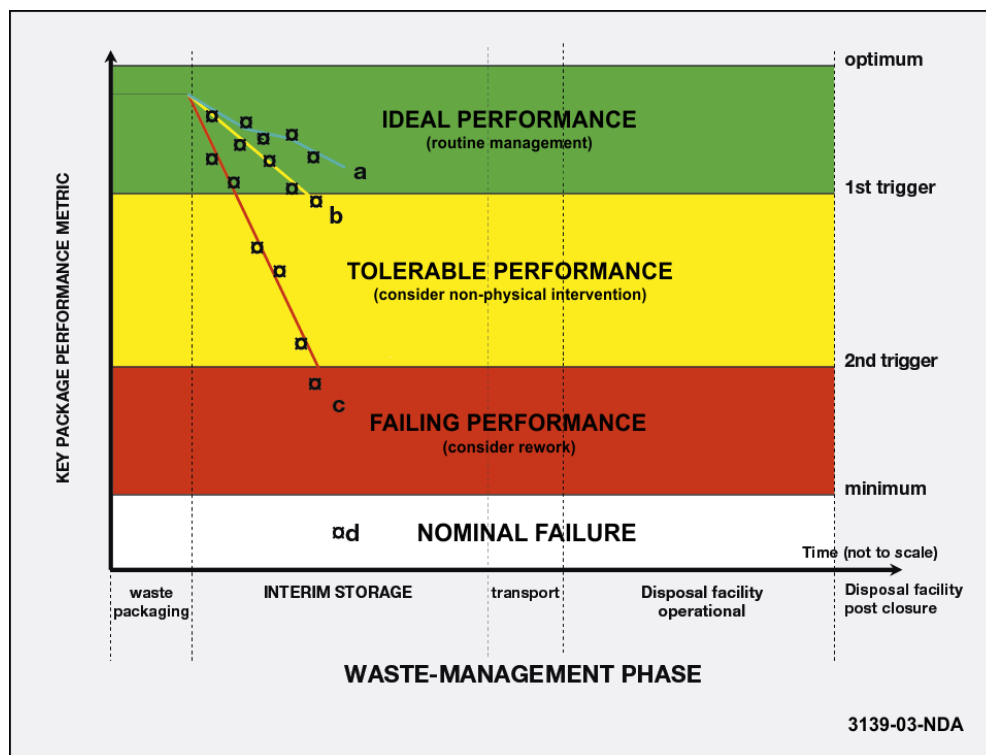


Figure 15 Hypothetical Patterns of Package Evolution

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

This will also have a bearing on appropriate tools. For example, issues relating exclusively to Group III and IV occurrence may benefit from changes to environmental control as discussed in subsection 5.4.

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 3.2.2. Examples of stylised package evolution are shown in Figure 15, which also includes a hypothetical 'envelope' of performance expected at the time the LoC 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 environment 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 3. 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 4 - will include consideration of the following factors:

- the gradient of any decline in performance, as measured by a monitoring parameter, and when the 2nd trigger level is likely to be crossed with respect to the overall lifecycle;
- the extent, if any, to which the actual performance is outwith the expected performance envelope;
- whether it is defined to be 'out-of-specification' with respect to WAC;
- the number of packages and safety functions affected;
- the categorisation of the package [29];
- availability of reworking facilities - see subsection 5.3.4; and
- expected export timing / or other planned package movements.

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 environment controls are likely to be necessary - see subsection 5.4.

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 3 - and followed up by appropriately timed rework, see case (b) criteria and toolkit in Table 4, 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 environment controls should also be carried out to control future evolution - see subsection 5.4.

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 safety function(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 [29] and related hazards;
- number, location of packages affected, and category (Type I to IV);
- availability of reworking facilities - see subsection 5.3.4;

- risks from intervention versus 'do nothing';
- internal stakeholder views - see GP3 (Technical competence) and GP22 (Package sentencing groups);
- 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 5. 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 6.

Given the anticipated rarity in encountering unexpected performance it is especially important that any event is well documented. GP1 (Stakeholder engagement) is highlighted in this regard. The Store Operator will need to have adequate arrangements in place to determine an appropriate approach to meet these eventualities.

Additional guidance to determine appropriate tools is outlined in Reference [80]. The possibility of deploying multiple techniques in parallel and or series should be noted. The techniques are in approximate order of increasing impact and cost. Generally, the intervention tool chosen should represent the minimum impact technique that is capable of either: underpinning a permanent and potentially higher impact response, or restore the safety function. Many of the identified tools will require the availability of space within the store if not available elsewhere on site. See GP23 (Maintaining contingency space).

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.
- 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.
- e) Invasive Physical Reworking. In which any action seeks to restore the safety function(s) by direct contact with and/or changing the wasteform.

For Type I and Type II evolution, and where the cause is known, the following baseline techniques are recommended:

- In the tolerable zone - additional monitoring to establish the 'rate of change' more accurately. If performance continues to decline, and reworking is required, and it relates to small areas of the package then localised repairs be carried out to restore the safety function otherwise 'overpack' as for a failing package; and
- In the failing zone - overpacking is likely to be a suitable method to restore overall package safety function for a wide variety of processes at least for unshielded packages. However, it does not treat the underlying cause. It may also hamper additional monitoring and inspection. Repeated overpacking, 'Russian doll' approach, is unsustainable. Under such circumstances overpacking should only be considered as a temporary measure until a more sustainable method can be deployed.

See subsection 5.4 for suggested toolkit for Type III/IV evolution.

Table 5 Non-Physical Intervention ToolkitTK13

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
Low Implication
Additional inspection on relevant in-store dummy packages
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 6 Physical Intervention - Reworking - ToolkitTK14

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

5.3.4 Location of rework facilities

Store Operators should consider making provision for access to credible reworking facilities. See GP25 (Access to rework facilities). Possible locations for rework facilities are identified as:

- in-store - with provision for import of equipment within a reserved space of the store OR with permanent equipment installed in a dedicated area;
- on-site - with mobile facilities transported to site as necessary OR in a nearby facility such as packaging/processing plant or neighbouring store with suitable capability; and
- off-site - at a GDF or other disposal or processing facility.

5.4 Approach A18 - Maintaining Environmental Conditions

Approach A18 (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 6.3.2, 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;
 - (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;
- (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 Tables 3 and 4.

A toolkitTK15 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 A19 - Maintaining Store Life-limiting Features

Approach A19 (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 [81] 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:

- a) the integrity of the storage facility and life-limiting components, for the required duration;
- b) the ability to control the environmental conditions;
- c) the ability to operate the store and manage packages;
- d) 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. See GP 4 (Asset Management) and GP26 (Extending store operational lives).

In line with GP 4 (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 [14] and also IAEA Report [82]. 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 [83]).

5.6 Approach A20 - Extending Store Lifetimes

Approach A20 (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 [61] and includes the following steps:

- correct diagnosis of the cause of any damage/failure;
- selection of a repair approach that addresses the cause;
- choice of appropriate repair materials and methods;
- management of the diagnosis and repair process; and
- post repair maintenance approach supported by comprehensive records.

For each generic life-limiting component a toolkit TK16 for remediation and/or replacement is described in Reference [61] taking account of various potential ageing processes which might affect the components.

6. Storage System Assurance

This section comprises of 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 dummy packages and inactive samples and simulants
- Benefits from periodic LoC reviews and audits
- Knowledge management and record keeping
- Maintaining SQEP resource into the future

6.1 Overview

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

- a) demonstrating to the Store Operator and their stakeholders, including Regulators and RWM, that the system is 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;
- c) providing an opportunity to demonstrate 'strategic learning' of the performance of different storage systems to inform future store designs and current operational practices.

All storage systems should have a well underpinned monitoring and inspection approach. This should be proportionate to the 'risk' from the waste packages [29] and the operational experience of the storage system type. Innovative storage systems and stores with the most challenging waste packages should have a greater emphasis on monitoring and inspection. Should results arising from monitoring and inspection be consistent with expectations, then, with time the frequency of inspections may be reduced in dialogue with the Regulators and RWM.

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 6.2;
- monitoring and inspection - see subsection 6.3;

- monitoring and inspection rates - see subsection 6.4;
- archiving - see subsection 6.5;
- inactive waste package simulants and samples - see subsection 6.6;
- auditing - see subsection 6.7;
- knowledge management - see subsection 6.8; and
- human resources - 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;
- regularly engage Regulators and RWM to ensure the proposed and implemented tools meet their requirements;
- ensure the waste package design and proposed arrangements have been assessed through the disposability assessment 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; 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).

6.2 Approach A21 - Baselineing

Approach A21 (Baselineing) [84], outlined in Figure 16, describes steps to establish the baseline condition of the storage system.

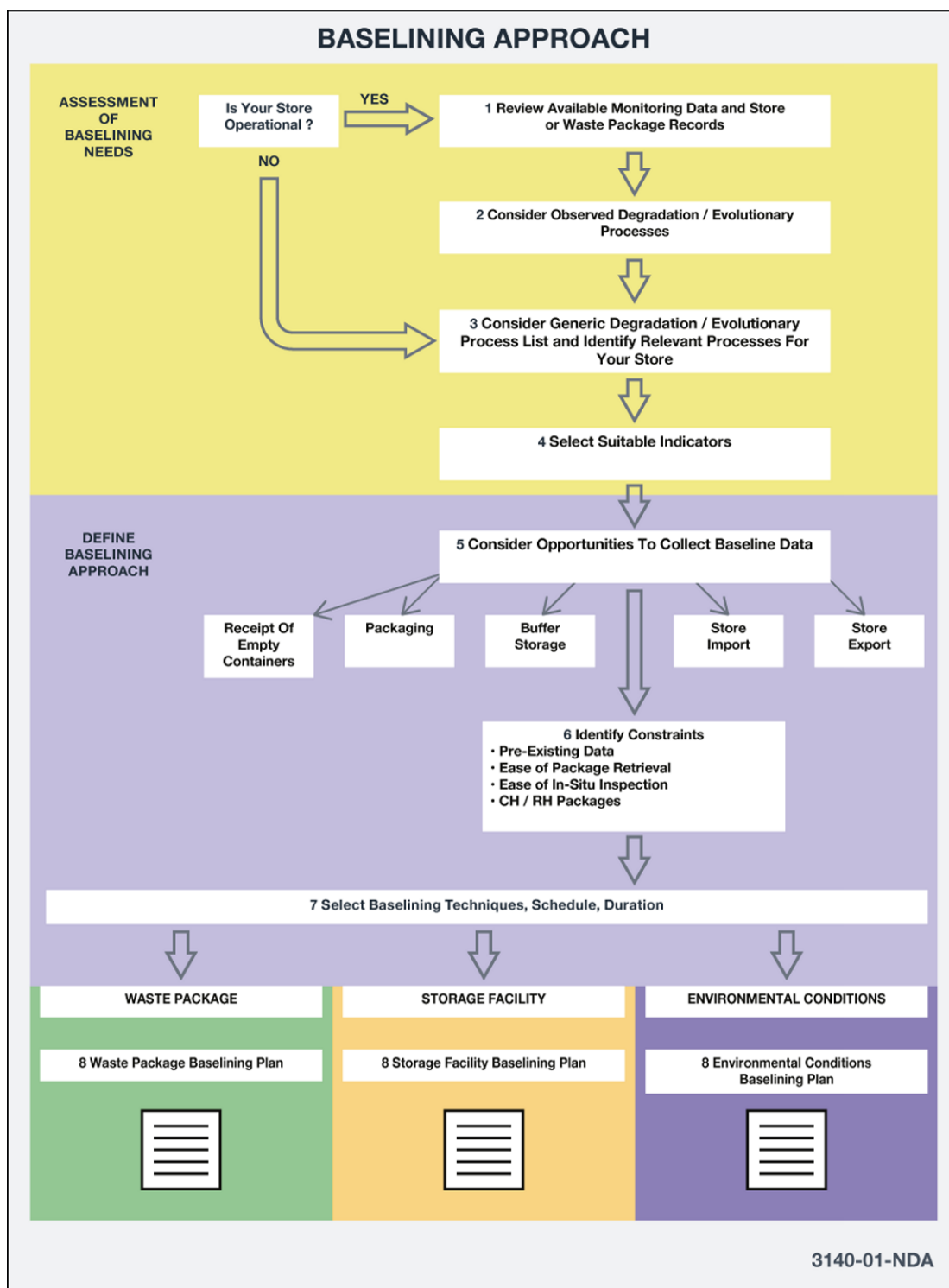


Figure 16 Schematic Representation of Approach A21

The baseline condition relates to each of the storage system components. Once established any departure from these initial conditions can be detected through regular monitoring and inspection as described by A22 (Monitoring and Inspection Techniques), and any necessary intervention can then be planned using A17 (Maintaining Package Safety)

Functions), A18 (Maintaining Environmental Conditions), and A19 (Maintaining Store Life limiting Features). Thus, A21 consists of:

- Reviewing, for an existing storage system, available monitoring data and records and consider observed evidence to date for evolutionary phenomena for the system components. Compare this list with generic phenomena described in the Guidance, information arising from engagement with RWM, and store safety cases reviews, and amend as necessary;
- Identifying, for a new storage system, a list of plausible evolutionary phenomena based from generic phenomena described in the Guidance, information arising from engagement with RWM, and store safety cases reviews;
- Identifying safety functions and life-limiting features threatened by relevant evolutionary phenomena and prioritise these [A6 (Package Evolution and Assessment), A9 (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 opportunities for baselining, considering each stage of the store and waste package lifecycle such as receipt of empty containers, production of waste packages, buffer storage, store import, store export;
- 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;
- 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 TK17 is described in Reference [85] to support Best Available Techniques (BAT/BPM) assessment.

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:

1. on receipt of empty containers;
2. during and after production of the waste packages; and
3. during 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. See also GP27 (Establishing system baselines) and A3 (Modifications to Existing Stores).

6.3 Approach A22 - Monitoring and Inspection Techniques

Approach A22 (Monitoring and Inspection Techniques) describes steps to establish a robust monitoring and inspection regime:

- a) Selecting sample types TK18. These include:
 - a. in-situ components of the storage system, i.e. packages - see subsection 6.3.1; life-limiting components - see subsection 6.3.2; store environment - see subsection 6.3.3;
 - b. full scale simulants or copies of system components, e.g. 'dummy packages' held under relevant store conditions - see subsection 6.6.1;
 - c. reduced scale simulants of system components, e.g. coupons of key components held under relevant store conditions - see subsection 6.6.2.

Additional sources of relevant information may include:

- storage system components held in other relevant stores;
- storage system components maintained in archives, see subsection 6.5;
- analogue materials either in a store or elsewhere, see subsection 6.6.3;

- use of 'canary' materials, in a store, which may be more sensitive to store conditions than the actual storage system components so as to provide 'lead times' or 'early warning'; and
 - use of pre-aged materials so as to provide 'lead times' or 'early warning';
 - deployment of modelling and theoretical studies.
- b) Selecting attributes to discriminate between potential monitoring and inspection techniques as part of a BAT/BPM demonstration. Recommended attributes include:
- Safety function related, such that output information can be related to the performance of the safety functions, see also subsection 3.2.2.
 - 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.
 - Credible, such that the technique has a high Technical Readiness Level (TRL) in the nuclear industry or widespread application elsewhere.
 - Predictive value such that the information may forewarn of future issues such that any intervention required is straightforward and can be adequately planned.
 - Reassurance value such that the output utilises recognised metrics which may reassure a wide range of stakeholders.
 - Reliable, such that false positive and false negative results are avoided.
 - Interpretable, such that any output should require limited interpretation to minimise potential human error.
 - Lifetime cost, which should be proportionate to the risks mitigated.
- c) Selecting tools from relevant toolkits. See subsections 6.3.1-6.3.3.
- d) Establishing frequency of monitoring and inspections. See subsection 6.4.
- e) Sharing results with other store operators, see GP28 (Recording system performance).
- 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 reduce inspection rates.

A22 (Monitoring and Inspection Techniques) as applied to packages, is represented in Figure 17.

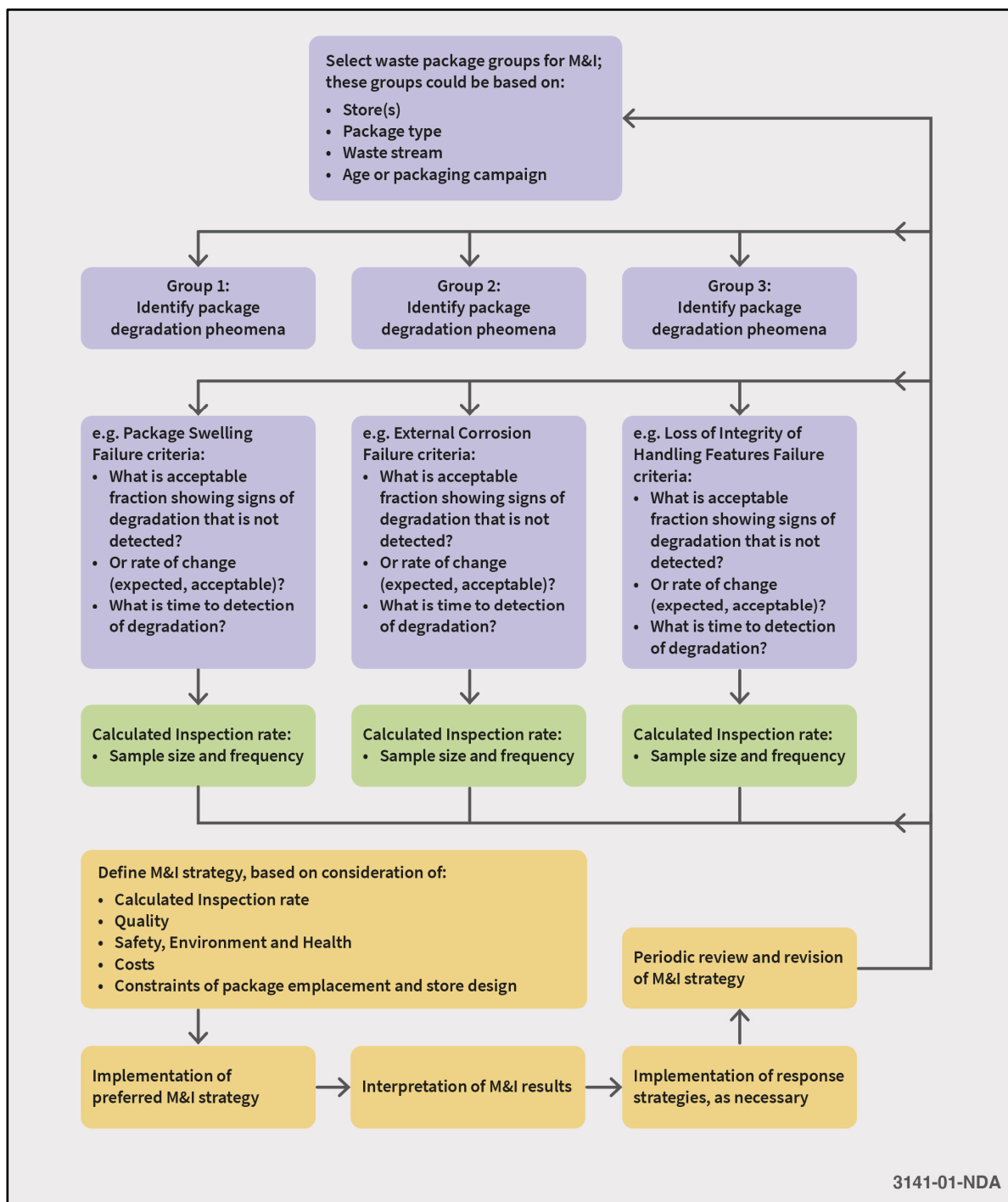


Figure 17 Simplified Flowchart of Approach A22 (Monitoring and Inspection Techniques) Applied to Waste Packages

6.3.1 Packages

A toolkit, TK19 of over 50 techniques with the potential to provide useful information concerning the evolution of waste packages has been identified, see Reference [86]. 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 3.2.2 - in addition to the other attributes noted in A22 (Monitoring and Inspection Techniques). For existing stores, with remote handling constraints, the incorporation of additional monitoring and inspection technologies may be extremely limited. Under such circumstances, greater emphasis should be placed on practicable techniques which minimise disruption in addition to use of information gleaned from other store operations.

Further, the potential for damaging packages during monitoring and inspection operations, and the radiological doses associated with deploying the selected tool needs to be considered as part of an ALARP argument.

In all cases comprehensive records must be made of the actual measurements and their interpretation and reference to these made in appropriate package records. Such data should be shared with other store operators so that strategic benefit can be realised using a standard reporting format.

6.3.2 Environmental conditions

Installation of monitoring equipment is best incorporated at the earliest opportunity. Monitoring equipment will require maintenance, calibration and testing to ensure accurate results are obtained.

The ability to monitor the environment can provide valuable information concerning the effectiveness of the overall storage system, and whether it is operating as expected - see subsection 5.4. Measurements should be made to provide a statistically significant average of internal conditions, as well as at key locations throughout the store which may provide diagnostic information, for example, near ventilation inlets and outlets. Measurements, external to the store and in other site facilities, e.g. without environmental controls, should also be made to provide a comparison with; this may inform any necessary changes to the environmental controls.

A toolkit TK20 of environmental monitoring techniques is provided in Reference [61]. Good records must be made of the measurements and reference to these made in appropriate waste package records. Both the absolute value of the measurements and commentary of its variation with time, noting any periodicity and spatial variation, should be recorded. Results should be shared with the SOF - see GP28 (Recording system performance).

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, conductivity measurements 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.

- b) Concentration of gases. Monitoring for gases with potential explosive, radioactive, toxic or corrosive effects should be carried out while there is a credible risk - see also subsection 3.3.3. Notably, radon gas concentrations measurements, before and after commissioning, should be made [27]. Monitoring gas concentrations (particularly H₂ but also H₂S) is also valuable in confirming the nature and rate of corrosion processes within waste packages. This is particularly important for wet non-encapsulated waste.

An example of a study of environmental conditions within an operational store, sponsored by RWM, is provided in Reference [87]. This includes a description of tools deployed, results gleaned and interpretation.

6.3.3 Store life-limiting components

It is a Licence Condition (LC28) 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 condition of the 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)".

Provision for maintenance, testing and inspection should be established to address the ageing of structures, systems and components and that 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 TK21 and shielded TK22 stores are identified in Reference [61] respectively for a range of store life-limiting components. Processes affecting concrete and reinforced steel evolution and monitoring technologies are outlined in Reference [88]. 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.

6.4 Approach A23 - Monitoring and Inspection Rates

Approach A23 (Monitoring and Inspection Rates) describes steps to determine a robust level for inspection and monitoring of waste packages and is illustrated in Figure 17. 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 of package storage across the period of interim storage, and that the actual frequency proposed 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).

6.4.1 Waste package

A23 (Monitoring and Inspection Rates), which is widely applicable to all storage contexts, is described in detail in Reference [89] along with a supporting toolkit TK23 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.

As shown in Figure 17, A23 (Monitoring and Inspection Rates) comprises a number of steps including:

- a) selecting common groups of packages;
- b) establishing relevant package evolutionary processes for these groups, see A6 (Package Evolution and Assessment);
- c) applying A1 (Package Performance), and selecting appropriate monitoring and inspection tools. Where information about a process, which may affect a required safety function can be obtained, it is recommended that a Bayesian statistical method is used. These 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.

For the Bayesian method, each common group of waste packages will need to have estimated distributions for each parameter to be monitored. Where this information cannot be reliably obtained, a simpler sampling method can be used based on classical probability theory, but this may result in a larger number of samples being required to achieve the same level of confidence;

- d) defining an inspection rate based on sample size and inspection frequency;
- e) applying cost benefit analysis, see example in Reference [89], to assess the practicability of implementing the proposed package monitoring and inspection approach. The outcome of such an analysis might suggest that the rate proposed is impracticable. In which case the approach should be used to establish the confidence level, and the use of inactive samples exploited as fully as practicable;
- f) implementing agreed monitoring and inspection regime;
- g) interpreting output, recording and sharing of results;
- h) reviewing applied 'approach' periodically.

For existing stores with an already established monitoring and inspection rate, it is recommended that A23 be considered when the current approach is next periodically reviewed.

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. The cost benefit analysis takes into account factors such as the expected long-term package performance, 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:

- use of dummy packages - see subsection 6.6.1;
- exploitation of reduced scale samples and simulants - see subsection 6.6.2; and
- sharing monitoring and inspection results from similar stores to maximise learning via the SOF.

6.4.2 Store environment

Continuous monitoring, as opposed to periodic inspections, of the store environment is generally appropriate for many environmental parameters which may be subject to daily and seasonal cycling. Unless the store environment is demonstrably stable and/or predictable (e.g. through a robust environmental model in combination with suitable

baselining), the frequency, quantity and scope of environmental measurements are unlikely to be greatly reduced with time as demonstrating a stable environment helps assure package and store life-limiting components. The inspection frequency of coupons, used to support environment monitoring, may be defined using A23.

6.4.3 Store life-limiting components

For civil structures inspection should routinely be carried out at least every five years (see [81], 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. Maintaining lifting equipment is a key enabler to ongoing store operations, see Reference [90] and extract, and more regular inspection may be necessary.

6.5 Approach A24 - Archiving

Approach A24 (Archiving) outlines types of materials which might usefully be maintained to assure the storage system and support timely and safe export. It is recommended, see GP30 (Maintaining an archive), that each store develops an archiving plan which identifies archiving needs and how the Store Operator will retain access to:

- b) 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.
- c) 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. Such an archive should be in a low radiation field environment but be under controlled conditions in an auxiliary part of the store.
- d) 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 [91]. These could be placed in any spare full scale container (dummy packages) within the store, or a low-radiation field environment 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 6.6.
- e) Records. Copies of the package records and store performance might usefully be retained as part of the storage facility.

6.6 Approach A25 - Inactive Samples and Simulants

Approach A25 (Inactive Samples and Simulants) describes opportunities to exploit the value from inactive waste package simulants and other storage system samples. Each store should develop a plan that describes the intended use and management of inactive samples and simulants across the store's lifecycle. The principal advantages from using simulants and samples is their cost effectiveness and potential for reduced worker doses compared with like-for-like inspections of actual packages and potentially inaccessible life-limiting components, see also Reference [92].

Simulants and samples should be retained and information about them shared with other Store Operators to maximise their strategic value. Any decision to discontinue the storage of inactive samples and simulants should be made strategically, see GP8 (Package materials), and offered to other stakeholders such as RWM for long-term stability underpinning, and universities carrying out fundamental research, before being disposed of.

6.6.1 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 [92] and otherwise support store operations with minimised operator risk. The specific potential benefits from deploying dummy packages, which are non-radioactive full-scale packages that are demonstrably representative of active waste packages as produced, include:

- A. Improving the knowledge base on package evolution. Used in this context it is important that the package is a realistic simulant of the active waste package(s), especially the wasteform, or can be readily related to such packages. The possibility of additional instrumentation within the dummy package to be provide evolutionary in-situ information, which may not be practicable for active packages, is noted. Dummy packages may also be used to forewarn of unexpected package evolution thus providing 'lead time' samples. While dummy packages may be most effectively deployed early in the stores' active commissioning phase, it is noted that any significant later updates to waste product specifications may justify additional or replacement dummy packages. Information arising from dummy packages not held within the store may also be usefully applied.
- B. Storage environment measurements. Instrumented dummy 'containers' may be used to augment the environmental monitoring regime, and be especially valuable in shielded

- stores, providing a route for direct measurements of contaminants on realistic surfaces. If used exclusively in this context, the wasteform simulant chosen is usually unimportant.
- C. Test packages to support store operations. If used exclusively in this context, choice of the wasteform simulant will be less important and it may be permissible to utilise containers otherwise deemed unsuitable for use as part of an active package, e.g. heavy scratches. Specific uses include: deployment as part of the commissioning process for import and export, store modifications, maintenance - notably of lifting features, maintaining SQEP of store operatives, and developing package intervention and reworking tools - see subsection 5.3.

6.6.2 Reduced-scale simulants and samples

It may not be economically viable to deploy sufficient dummy packages in a store so as to be statistically representative of the full range of active packages, or properly represent spatial variations of environmental conditions within a store. Instead, reduced scale inactive simulants can be deployed within the store and/or under controlled conditions in other facilities to provide similar information to dummy packages, i.e.:

- Improving the knowledge base of package and life-limiting components evolution. After identification of relevant evolutionary processes, using for example A1 (Package Performance) and A6 (Package Evolution and Assessment), samples of relevant materials may be left in easy to access positions in the store or elsewhere to support effective monitoring and inspection.
- Storage environment measurements. Corrosion coupons, see for example [93], are often deployed in stores to measure contaminant deposition. It is recommended that these are deployed throughout the store, including near ventilation inlets and outlets and to explore spatial variations.

A suite of documentation, including a sample database, [91] is available which describes the deployment of inactive samples across the lifecycle and package designs. There are over 8000 samples, mostly wasteform related, which cover most current UK packaging concepts and many are up to 30 years old. They include a wide range of simulant wasteforms and encapsulants, containers and metallic wastes. Many of the samples have been irradiated to high levels of dose well beyond that expected during interim storage.

While the benefit from the samples is largely strategic, i.e. demonstrates the sustainability of the UK baseline for waste packaging, there are a number of specific benefits, including:

- early warning of evolutionary processes, including accelerated ageing and using 'canary materials' which are more sensitive to the environment than employed materials;

- direct insight to how the wasteform is evolving including destructive testing and supporting fundamental understanding of evolutionary processes;
- exploration of extreme formulation envelopes; and
- testing of innovative materials using a standard testing approach to establish underpinned baselines.

Most of these samples are held under laboratory conditions. A proportionate approach, based on the categorisation of the waste package, is described in Reference [94] for the design, production and addition of samples to the long-term monitoring programme and is outlined in Figure 18.

For container corrosion experiments, a single small-scale package can usually provide sufficient re assurance of long-term internal corrosion trends. All experimental trials normally require four to eight samples to provide sufficient control and duplication of results. In contrast to long-term monitoring samples, irradiation tests inevitably require expert consideration to conceive suitable testing plans. In some cases (processes controlled by total dose) accelerated tests to achieve the full lifetime dose at a very accelerated dose rates may be appropriate. In other cases, testing at a suitable dose rates, or a combination of tests achieving both realistic doses and realistic dose rates, are required. An example of relevant considerations is described in Reference [95].

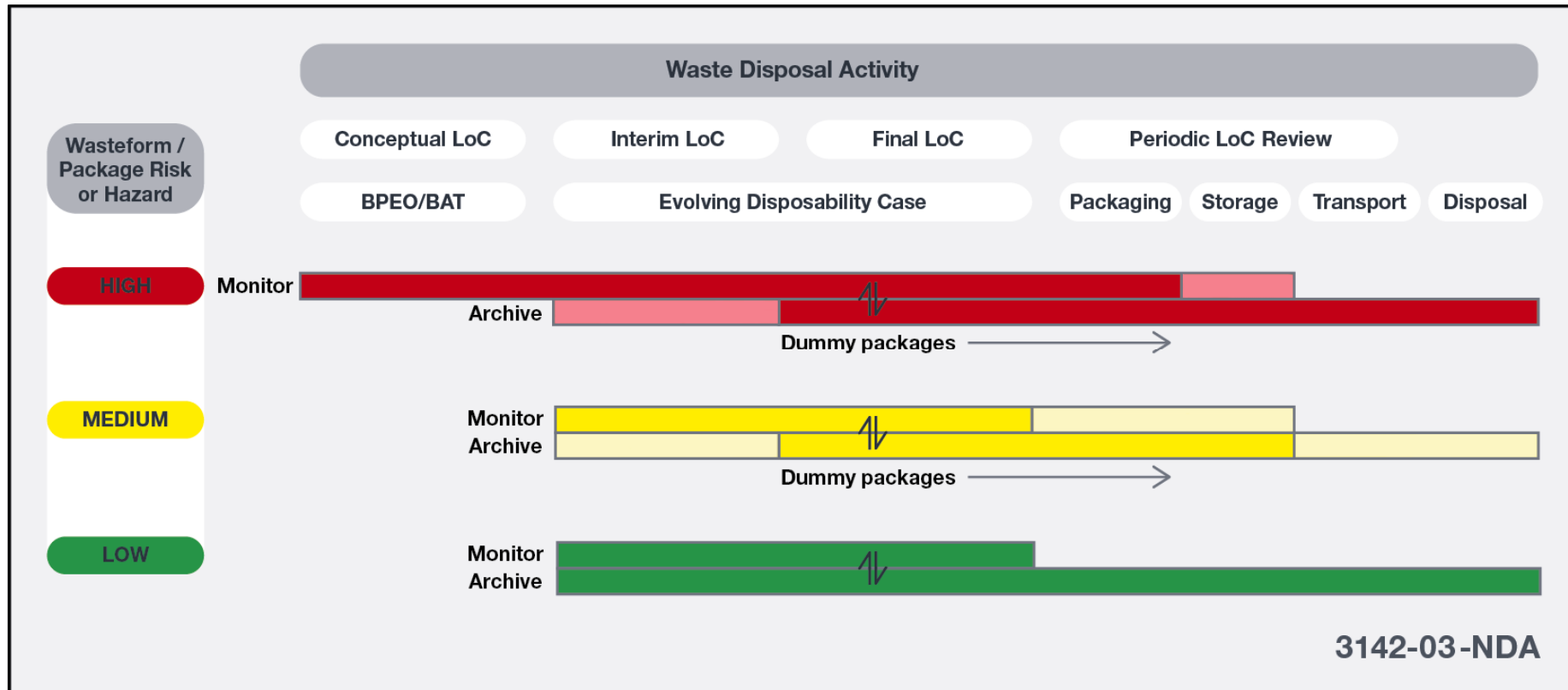


Figure 18 Recommended Timeline for Sample Addition by Waste Package Category

6.6.3 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, and similar materials utilised under harsher conditions such as on oil rigs, and coastal structures like piers and bridges.

6.7 Approach A26 - Auditing

Approach A26 (Auditing) concerns demonstrating, so far as is reasonably practicable, that:

- packages remain in a form suitable for disposal either directly or, if required, after planned finishing operations;
- suitable plans are in place to ensure that provisions are made for eventual transport to the GDF, particularly if further finishing operations may be required

Store Operators should ensure that package performance records associated with the relevant LoCs are maintained throughout the storage period, and any conditions attached are observed. To provide additional assurance, RWM expects to carry out periodic reviews of final LoCs, at a flexible frequency, with a recommended time interval of not more than 10 years [96].

The detailed scope of the review should be determined by the licensee and RWM. While the remit of periodic review is broader than interim storage, and ultimately seeks to revalidate the currency of the LoC and maintain the disposability case, the following aspects of the review are noted:

- whether conditions, restrictions and caveats on the LoC have been observed;
- the status of the quality management systems employed by the Store Operator;
- the condition of stored waste packages, compared with expectations;
- the condition of the waste store, and any excursions outside OLCs during the life of the stored waste package
- the maintenance of appropriate package records;
- any emerging issues since the final LoC was issued, or previous review;
- consistency with and adequacy of store WAC; and
- whether any changes to the store safety case may have implications or relevance to the disposability case. It should be noted that stores will be subject to periodic safety case review throughout the operational life of the store ensuring any necessary and timely improvements are made.

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.

6.8 Approach A27 - Knowledge Management

Approach A27 (Knowledge Management) outlines steps to ensure effective knowledge management, including but not limited to records management across the storage system's lifecycle noting the inter-generational timescales. See, for example, Reference [97] and [98] for guidance on long-term records management. Some of the knowledge management practices noted below may be the responsibility of the Licensee rather than the Store Operator.

Knowledge management practices should be deployed throughout the store lifecycle from the conceptual design through to decommissioning. Knowledge management practices should also support the development and maintenance of competence to operate throughout the store lifecycle.

A well-thought approach to knowledge management may be particularly important for interim products, for which additional downstream operations benefitting from a good understanding of the design and content of waste packages may be planned before final disposal. In this case, the use of learning plans focusing on things which store operators wish to learn (or develop further understanding of) during interim storage to inform a wider set of decisions around finishing and future disposal, could be desirable. The learning plans would need to provide a description of the information subjected to learning, its expected value and future use, and a description of the approach to acquiring such information during interim storage. They could also consider the infrastructure required to enable the learning to be captured and, more broadly, be integrated with CM&I plans. See Approach A4 for further details specific to interim products. 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 6.9;
- lessons are captured, retained and acted upon;
- valid records of contents and plant configuration are kept and are retrievable and interpretable throughout the lifecycle of the store; 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:

- a) Ensure that store sites are mapped and described so that their locations, configuration and the inventory can be established at all times. Sites should be physically marked with universally recognisable signage compliant with IAEA guidance.
- b) Processes are in place to ensure that information ownership is maintained and transferred during management and operational transitions over the full lifetime.
- c) Undertake critical knowledge audits to manage knowledge risk, establish baseline and future requirements and the necessary management actions to fulfil those requirements. These need to be repeated at intervals of no more than 10 years.
- d) Maintain essential proficiency by, inter alia: training and coaching, R&D, targeted recruitment and supply chain engagement.
- e) Maintain accessible libraries of documents, images, videos, drawings, graphs, other information artefacts and knowledge assets.
- f) Maintain interaction with national and international communities of practice.
- g) Undertake knowledge risk assessments of personnel and groups that hold critical knowledge and establish plans to retain that knowledge (succession planning).
- h) Systematically capture, retain, resolve and share lessons learned through national and international collaborations between operators and regulators.
- i) Maintain, 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.
- j) Maintaining records of the operation of the storage system including package records [29] and applicable dummy packages, simulants and samples.
- k) Create a plan for the long-term preservation of information to manage the inevitable series of media obsolescence over the total operating period of the facility.

Additionally, Store Operators are referred to a top down approach developed by the NDA [99] 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. Attention is also drawn to the importance of maintaining RWMCs to provide an accurate overview of HAW management on each site [29].

6.9 Approach A28 - Human Resources

Approach A28 (Human Resources) comprises the following considerations.



The NDA has published its People Strategy (incorporating Skills and Capability) [100]; see also Reference [10]. These documents highlight the importance of skills development and training, developing and maintaining networks and setting standards.

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. A skilled workforce must be available to support ongoing storage activities such as monitoring and inspections, planned maintenance, reviewing safety cases and package exports. Over time the number of stores will increase and is therefore likely that an important storage activity will be going on somewhere within the UK at any one time. Therefore, NDA and other waste owners may want to consider a number of workforce planning options including:

- 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;
- a 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.

Therefore, Store Operators should maintain a watching brief concerning industry-wide initiatives and ensure that future resource needs, informed by the Guidance, are represented through the lifetime plans of the Waste Owner.

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).

GP	Description	Subsection
1	<p>Stakeholder engagement. The Regulators and RWM 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 [Error! Bookmark not defined.].</p> <p>Relevant to all storage systems, especially for proposed new packages and stores, and modifications to existing storage systems.</p>	1.4.3; 1.4.4; 5.3
2	<p>Technical terminology. Consistent technical terminology should be used to describe all aspects of the storage system across its lifecycle.</p> <p>Relevant to all storage systems.</p>	2.1
3	<p>Technical competence. Throughout the period of interim storage, SQEP should be available, who:</p> <ul style="list-style-type: none"> • 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 RWM 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. <p>Relevant to all storage systems. Noting there is greater potential to share SQEP between common storage systems.</p>	2.1.3a; 3.2; 5.3
4	<p>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.</p> <p>Relevant to all storage systems and stages of the lifecycle.</p>	2.1.3b
5	<p>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.</p> <p>Relevant to all storage systems.</p>	4.2, 5.3.1, 5.5
6	<p>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.</p> <p>Relevant to all storage systems, noting the likelihood that unique designs will more likely require bespoke R&D.</p>	2.3.1
7	<p>Peer groups. The Store Operations Forum should be regularly engaged to share and benefit from operational 'lessons learned'.</p> <p>Relevant to all storage systems and stages of the lifecycle.</p>	2.3.2

GP	Description	Subsection
8	<p>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.</p>	3.1
9	<p>Package materials. On the basis of available operational information over the last 20+ years, currently used austenitic stainless steel grades are considered suitable materials for containers under the controlled environmental conditions in current UK stores. 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.</p> <p>Relevant to planned storage systems considering materials and/or environmental conditions for which there is limited operational experience.</p>	3.1; 6.6
10	<p>Maintaining transportability. A clear linkage should be provided and then maintained between the transport safety case and the storage safety case to reduce the risk that packages may not be transportable when required.</p> <p>Most relevant to storage systems comprising of any packages not reliant on a transport container such as a SWTC.</p>	3.1.3, 5.1.3
11	<p>Package evolutionary processes. Plausible evolutionary processes for all package types during storage should be determined and a recorded assessment made of the significance to the package safety functions. Package performance criteria should be derived for all package types.</p> <p>Relevant to all waste packages, and should be applied proportionately according to the categorisation - see [Error! Bookmark not defined].</p>	3.2.2
12	<p>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.</p> <p>Relevant to all waste packages and any storage system which may receive additional packages.</p>	3.4
13	<p>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.</p> <p>Especially relevant if containers or packages may be 'buffered stored', and during transfer or transport.</p>	3.4
14	<p>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.</p> <p>Relevant to stores being designed and planned.</p>	4.1.2
15	<p>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 categorisation of stored packages.</p> <p>Most relevant to future stores. Any opportunities to improve arrangement for existing stores should be considered - see A3 (Modifications to Existing Stores).</p>	4.1.3



GP	Description	Subsection
16	<p>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.</p>	4.2.2
17	<p>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.</p>	4.3.1, 4.4.2
18	<p>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.</p>	4.3.2
19	<p>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.</p>	4.4.1
20	<p>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</p>	5.1.1
21	<p>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 [Error! Bookmark not defined.].</p>	5.1.2
22	<p>Package sentencing groups. A packaging sentencing group should be established to advise on suitable actions to take concerning package performance issues across the lifecycle. 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 [Error! Bookmark not defined.].</p>	5.3.3



GP	Description	Subsection
23	<p>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 [Error! Bookmark not defined.].</p>	5.3.3
24	<p>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 environment controls. Relevant to all storage systems, especially those with high-category packages [Error! Bookmark not defined.] and where there is a high dependency on the environmental controls.</p>	5.3.3; 5.4
25	<p>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 is currently considered the most flexible method to deal with a wide range of plausible reworking scenarios for unshielded packages. Especially relevant to storage systems, with high-category packages [Error! Bookmark not defined.].</p>	5.3.4
26	<p>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. 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 HAW strategies were established.</p>	5.5
27	<p>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) 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.</p>	6.2
28	<p>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.</p>	6.3
29	<p>Monitoring inspection rates. A target rate of monitoring and inspection, to provide a high level of confidence over interim storage, should be established. Cost benefit analysis should be used to justify the actual rate proposed and the approach agreed with stakeholders. Relevant to all storage systems.</p>	6.4



GP	Description	Subsection
30	<p>Maintaining an archive. A strategic archive of spares and materials to inform future decision making should be established. The inventory should be recorded, updated regularly and made available to other Store Operators. 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.</p>	6.5
31	<p>Deployment of dummy packages. An optimum number of dummy packages should be established for each store, proportionate to package categorisation, monitoring/inspection benefits afforded, and any unique features or properties of packages in the store. It is recommended that all stores have access to at least one full scale representative dummy package to assist store operations. Information arising from dummy packages deployment should be shared. Relevant to all storage systems especially those with non-contact handleable packages and high-category packages [Error! Bookmark not defined.].</p>	6.6.1

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 2-4	For 3m ³ packages.
	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.
	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 FGMSF 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.
	MXL (multiple sites)	

Status	Store Name	Description
	ILW Store, Hunterston A	Active since April 2014 and has received over 1000 containerised packages (December 2020).
	Interim Storage Facility (ISF), Berkeley	Operational, taking DCICs. Making modifications to accept encapsulated packages including 6m ³ concrete boxes.
	ISF, Bradwell	Operational, taking DCICs from Dungeness.
	ISF, Chapelcross	Inactive commissioning underway. Store will take DCIC packages, overpacked, sealed 500-litre drums, overpacked TSVs and 6m ³ concrete boxes.
	ISF, Dungeness	Not being progressed. Packages being transferred to and stored at the ISF at Bradwell.
	ISF, Hinkley Point A	Being commissioned for 6m ³ concrete boxes, will also take DCICs.
	ISF, Oldbury	Not being progressed.
	ISF, Sizewell A	Not being progressed.
	ISF, Wylfa	Not being progressed.
	ILW Store, Trawsfynydd	Contains stillages with 1,941 '1803-type' drums of resin wastes, 124 concrete-overpacked 3m ³ boxes and 77 3m ³ drums (as of November 2020).
	Harwell ILW Box Store - HIBS	For decommissioning wastes in 6m ³ boxes – store being commissioned.
	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 now planned for disposal at LLWR.
	EDF Energy (multiple sites)	
	Sizewell B Store	Contains waste which is awaiting agreement and implementation of packaging proposals.
	AGR Sites (Hunterston B, Dungeness B, Hinkley Point B, Heysham 1 & 2, Torness, Hartlepool)	Proposed store at each site for packages of resin and sludge wastes; detailed packaging proposals to be agreed.

Key (as of 2020)	
	Operational store
	Under development
	Future or planned store



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 HAW 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.
buffer storage	short-term storage, up to about 10 years, of 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 which has been recovered or removed from its plant of origin and has been processed such that it meets the passively safe criterion for storage and/or disposal.
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 exempt from specific regulatory requirements.
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.
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 or has the potential to form part of a future disposal solution
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	conversion of waste into a wasteform by solidification, embedding or encapsulation.
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 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.
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.
thermal processing	use of substantial heat to render waste into a more passive form and/or to reduce the bulk volume.
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 intended to benefit safety and/or economy by changing 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 be bounded by the relevant safety cases, e.g. store and transport.



waste container	the vessel into which the wasteform is placed 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 or any added inactive capping material.

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
An	Approach n
AGR	Advanced Gas-cooled Reactor
ALARP	As Low As is Reasonably Practicable
AWE	Atomic Weapons Establishment
BAT	Best Available Technique
BEPSS	Box Encapsulation Plant Product Store
BPEO	Best Practicable Environmental Option
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 (of England and Wales, compare with SEPA and NRW)
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
GWPS	Generic Waste Package Specification
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
IRR99	Ionising Radiations Regulations 1999
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
MBGWS	Miscellaneous Beta Gamma Waste Store
MIC	Microbiologically influenced Corrosion
MoD	Ministry of Defence
MRWS	Managing Radioactive Waste Safely
MXL	Magnox Limited
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
NRW	Natural Resources Wales (compare with EA and SEPA)
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 (compare with EA and NRW)
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
WPSGD	Waste Package Specification and Guidance Documentation

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